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HULL BULLETINS
OF
MARINE ECOLOGY

VOLUME I

EDITED BY

A. C. HARDY, M.A., D.Sc., F.R.S.

Until recently Professor of Zoology and Oceanography in the University College of Hull, now Regius Professor of Natural History in the University of Aberdeen, and Honorary Director of Oceanographical Investigations at Hull

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Adlard & Son, Ltd.,
at their works, Bartholomew Press, Dorking.

PERIODICAL
(Hull) Bulls. Marine Ecology
2355^{60} V.1
(1-6)

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LIST OF PERSONNEL OF THE DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY COLLEGE OF HULL, 1931–1942

Head of Department :

Professor A. C. Hardy, M.A., D.Sc.(Oxon.), F.R.S.

(In 1942, on being appointed Regius Professor of Natural History in the University of Aberdeen, he was made Honorary Director of Oceanographical Investigations at Hull, and Dr. C. E. Lucas became Head of the Department, now separated from that of Zoology as a special research department.)

Research Biologists :

C. E. Lucas, D.Sc.(London), 1931–*

(Officer in charge of the Leith Laboratory since its foundation in1937, and became Head of Department in 1942 ; see note above.)

G. T. D. Henderson, B.Sc., Ph.D.(Bristol), 1931–†

J. H. Fraser, M.Sc., Ph.D.(Liverpool), Leverhulme Fellow, 1932–35*

K. M. Rae, B.Sc.(London), Leverhulme Fellow, 1935–†

W. Macnae, B.Sc.(Glasgow), 1937–1939‡

N. B. Marshall, B.A.(Cantab.), 1937–†

C. B. Rees, M.Sc.(Wales), 1937–†

H. G. Stubbings, M.A., Ph.D.(Cantab.), B.Sc.(London), 1939–*

Laboratory Stewards :

J. Hancock, 1930–35
J. Scrivener, 1935–†
F. H. Dewing, 1937–§

Laboratory Boys :

A. Robinson, 1931–35†
R. R. Warriner, 1935–41†

* Now engaged in scientific war research.
† Now serving in H.M. Forces.
‡ Was serving in H.M. Forces, but invalided out.
§ Now in war-time industry.

Names in italics indicate those members of Staff who have left the service of the Department.

The Science Building, University College of Hull.

PREFACE

The 'Hull Bulletins of Marine Ecology' are reports on investigations carried out by the Department of Oceanography in the University College of Hull. The College is supported in this work by grants from His Majesty's Treasury, made on the recommendation of the Development Commissioners, and from the Leverhulme Trustees, the Hull Fishing Vessel Owners' Association and the Fishmongers' Company (see acknowledgments in 'Bulletin' No. 1, p. 53).

The researches are being carried out in close co-operation with the Ministry of Agriculture and Fisheries and the Fisheries Division, Scottish Home Department (late Fishery Board for Scotland). They are not intended to be isolated investigations; it is hoped that they will be of service to the Fishery Departments, fitting in with their various research programmes and linking up with the general investigations of the International Council for the Exploration of the Sea. In order to maintain a close liaison a Joint Advisory Board, consisting of Dr. E. S. Russell, O.B.E., Director of Fishery Investigations, Ministry of Agriculture and Fisheries, Dr. R. S. Clark, Scientific Superintendent, Fisheries Division, Scottish Home Department, and Professor A. C. Hardy, was set up at the invitation of the

College in 1936 to advise on the future planning and development of the plankton recorder survey, which at present forms the main part of this Department's programme.

When the College was first planned it was intended that a research department should be established to be of service to the great fishing industry which is so well represented on the Humber at Hull and Grimsby. Oceanographic researches must often appear to members of the industry to be remotely removed from their immediate interests. Since reports such as the present 'Bulletins,' which are intended primarily as contributions to the scientific literature of the subject, will necessarily be too detailed and technical to be read by the layman, each volume will be accompanied by an explanation of its contents: a non-technical account pointing out its bearing on the future welfare of the industry.

The 'Bulletins' are not issued at regular intervals, but new numbers are published from time to time as the work develops. While it is hoped that the researches may be developed in several directions for a long period into the future, no guarantee of their continuation can be given; in the event of their coming to an end, the 'Bulletins' would be completed as a work of two or three volumes describing these particular investigations. Since work has been suspended for the war the future must be still more problematical; but sufficient funds have been put on one side to ensure the completion of at least two volumes. The first three 'Bulletins' were in the press and a further three were in an advanced state of preparation before the actual declaration of war.

Acknowledgments of all the kind help we have received in our work from so many people is given in a special section of 'Bulletin' No. 1. As Editor, I would here like to express our appreciation of the trouble the printers, Messrs. Adlard & Son, Ltd., of the Bartholomew Press, Dorking, have taken in the production of the volume, and of the skill of Miss E. C. Humphreys, who has converted all our pencil charts into the finished drawings of the plates which form so large a part of the book.

EXPLANATION

A non-technical account of the contents of the volume for the general reader, intended to show the bearing of the work upon the future welfare of the fishing industry

BY

A. C. HARDY, D.Sc., F.R.S., *Editor*

Pages vii to xv are an introduction to marine ecology in general.
Pages xvi to xlii describe the work at Hull and its relation to the fisheries.

It is not usual for a scientific journal to give space to what may be termed an essay in "popular science." As a reason I may quote from a lecture given at the University College, Hull, in the autumn of 1929 and published under the title of "Science and the Fishing Industry." In it I regretted that sometimes little interest was taken by the industry in scientific investigations but expressed the view that the blame lay as much with the scientist :

> "The results of these researches are published in 'blue books,' often quite unreadable by the layman. We scientists usually write for our colleagues who are working on similar problems, often working in other countries, and we write in a technical jargon of our own, often with a welter of statistics. Some of the plankton papers published look more like fantastic railway guides than accounts of life in the sea ; and even scientists have been known to sigh as they turn their pages. How can we expect the industry to understand and sympathize ? I think it would be a great service if the Government or the industry employed a trained person to summarize these papers in plain English. Again, and happily this is becoming more common, the scientist and the industry should come together. They both have their contributions to make to the sum of the knowledge of the sea. The fisherman with his life-long experience has much to tell the scientist."

This is an attempt at such an interpretation of the contents of this volume—a simple statement of what we are driving at. Since it introduces the first of our series, it must also be to some extent a short explanation of marine ecology in general.

MARINE ECOLOGY.

To begin with, what do we mean by "ecology"? It is often misunderstood. We may define it as the branch of science which studies the relations between living things, both animals and plants, and their surroundings; these include not only the physical world of air, water or soil, in which they live, but also all the other creatures which live round about them. Thus marine ecology not only deals with the kind of water in which we may expect to find, say, a particular kind of fish—warmer or colder water, coastal or oceanic water—but also deals with the relations between such a fish and a host of other forms of life: its enemies which prey upon it, the rival competitors for its food, and the food itself.

Many people on being given such an explanation would reply, "Surely this 'Ecology' is nothing more than a new-fangled name for what we have always known as Natural History?" No—simple natural history describes natural events as history does; it does not *measure* them as does a science, and we defined Ecology as a branch of science. When a naturalist records that a fish feeds upon various kinds of shrimps, that is a fact of natural history. When, after a prolonged investigation, involving the post-mortem examination of thousands of fish of different ages and at different seasons of the year, he can begin to deal in actual numbers, then he is making a contribution to Ecology: when, for example, he can say that this kind of fish takes ten times as much food in summer as it does in winter, or that its food on an average consists of 60 per cent. of one kind, 20 per cent. of another, and so on; or again that these proportions change with the seasons and with the age of the fish. The little bit of ecology, for instance, which concerns the quantities and kinds of food the herring feeds on in different areas is at present based upon the study of more than 50,000 fish by different workers. Ecology is establishing the relationships between a creature and its surroundings in terms of quantity. We shall see the great advantage of this as the discussion proceeds. It is not just the satisfying of scientific curiosity; it is the building of a framework of measurable fact which will in time be turned to practical ends.

But in singing the praises of modern ecology we must not underestimate the value of the older natural history. The naturalists are the pioneers, the advance guard; they describe the different animals and plants, and how they live. The ecologist follows up with instruments of experiment and various methods of analysis.

Ecology deals with the natural "economy" of the world of life. Let us consider that of the sea in its simplest terms. We have the sunlight shining down into the water and we have all the chemicals essential for plant growth—carbon dioxide and oxygen dissolved into the water from the atmosphere, and the no less important mineral salts derived from the land and spread throughout the sea. All plants need sunlight, so in the upper layers of the water, where the sunlight is strong enough, we find the plants of the open sea. They are not large, like the seaweeds of the shore, but are as a living dust scattered through the water:

specks of life in countless myriads, so small that they can be seen only through a microscope. In a shaft of sunlight slanting into a shaded room we have all watched the motes of dust floating in the air, floating because they are so small and light ; these tiny plants remain suspended in the water in just the same way, many of them being provided with little spine-like projections like thistle-down. The large seaweeds form a very small part of the vegetation of the sea : they are but a shallow fringe along the coasts.

Feeding upon these tiny floating plants, and also like them scattered through the sea in teeming millions, are little animals. Shrimp-like creatures of many different kinds predominate, mostly varying in size from that of a pin's head to that of a grain of rice, but some are larger. There are hosts of other kinds as well —small worm-like forms, miniature snails with flapping fins to keep them up, little jellyfish, and many more which surprise us with their strange and beautiful shapes when first we see them through the microscope.

All these, *both the animals and the plants*, which are floating and drifting with the flow of tides and ocean currents, are spoken of under the general name of *plankton*. It is a Greek word meaning simply *that which is drifted*. It is useful to have one word to distinguish all this passive drifting life from the creatures, such as fish and whales, which are strong enough to swim and migrate through the moving waters. Actually, when they are very young, the baby fish are strictly speaking part of the plankton, for they too are carried along at the mercy of the currents until they can swim against them.

A simple sketch in Fig. 1 shows the general economy of the sea in diagram form. Figs. 2 and 3 show photographs taken through a microscope of the plant and animal plankton which have been caught by drawing a net of fine silk gauze through the water.

Many fish, such as the herring, sprat and mackerel, feed upon these little plankton animals ; so also do the huge whales, which form the object of such an important fishery in the far south (they feed upon slightly larger, but still quite small, prawn-like animals which swarm in the polar seas). Even the fish living on the sea bottom fed on the plankton in their babyhood ; it is important to remember this.

From this world of planktonic life, dead and dying material is continually sinking to the bottom ; here, on the sea bed, we find a profusion of strange animals equipped with all manner of devices for collecting it. Upon these animals in turn feed voracious crawling creatures. Then all of these, worms, starfish, crab and lobster-like crustaceans, bivalve shellfish and many other less familiar kinds of life, form the food of fish which roam the sea-floor in search of them—the cod, haddock, plaice and the like.

Finally comes Man ; catching the herring and mackerel with his fleets of drift nets near the surface, hunting the great whales with explosive harpoons, and sweeping the sea bed with his trawl for the bottom-living fish.

We see how all-important the plankton is. All the life of the sea depends, for its ultimate supply of food, upon the meadows of floating microscopic plants—the plant plankton or *phytoplankton* as the scientist calls it. In the sea, just as on the land, it is the plants which are the producers and the animals the consumers. One animal may feed upon another, which has in turn been feeding upon other animals and so on; but ultimately they are all supported by those which feed upon the plants. The plant alone can live upon the simple mineral chemicals, building itself up and growing by using the energy of sunlight.

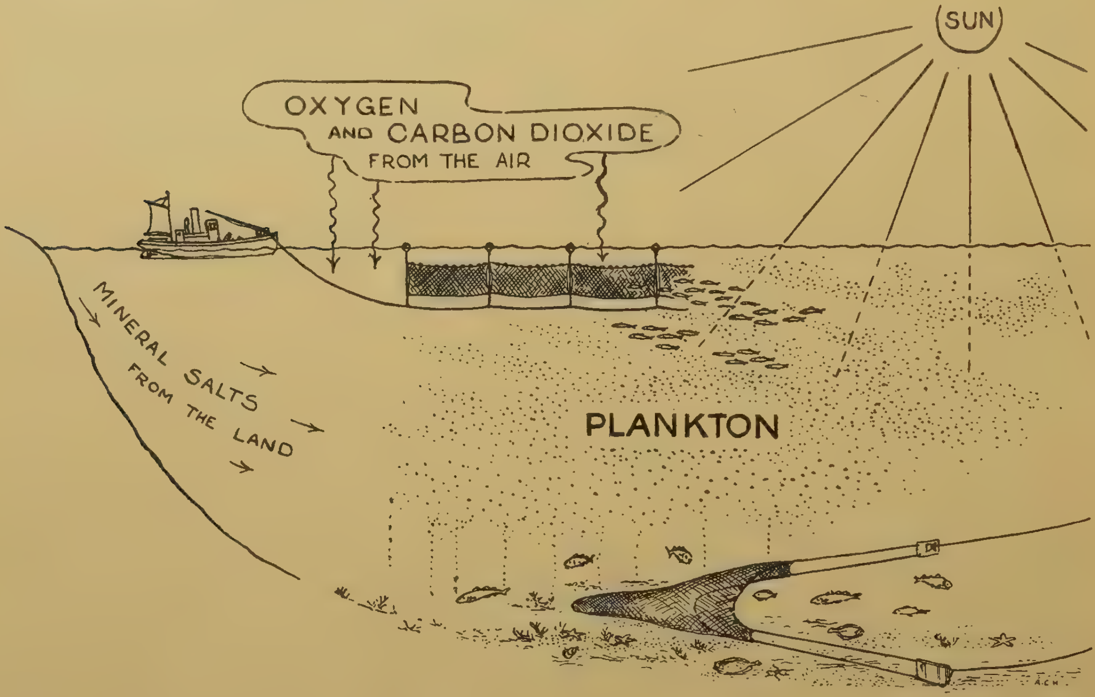
SUN
OXYGEN AND CARBON DIOXIDE FROM THE AIR
MINERAL SALTS FROM THE LAND
PLANKTON

Fig. 1.—Simple sketch of the natural economy of the sea, showing how the fisheries, both drift-net and trawl, are dependent upon the plankton which in turn subsists through the tiny plants upon the chemicals of the sea and the energy of sunlight. Plankton is the food of fish like the herring; it also feeds the animals on the sea-bed which are the food of trawl caught fish.

It is not surprising that at last we are beginning to realize the economic importance of studying these factors which underly this great production of fish and whale oil. The beginning of this century saw the formation of the International Council for the Exploration of the Sea; scientists of government (or government supported) institutions of the different nations of Europe began a series of investigations to form part of one great plan. Not only are they inquiring into the lives of the fish themselves, their life-histories, food and feeding habits, migration, growth, birth-rates and so forth; but, with continually improving equipment, they are studying the distribution of the different plankton forms, the conditions

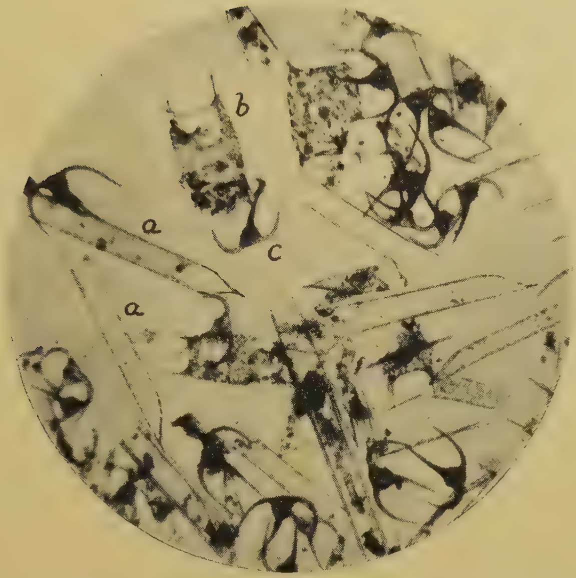

FIG. 2.—Some of the tiny plants (phytoplankton) as seen through a microscope magnifying them some 60 times (*i.e.* × 60 diam.). This sample shows (a) *Rhizosolenia styliformis* and (b) *Biddulphia sinensis*, both, when abundant, having an adverse influence on the herring fisheries (see p. xvi); also (c) *Ceratium* (one of the Dinoflagellates).

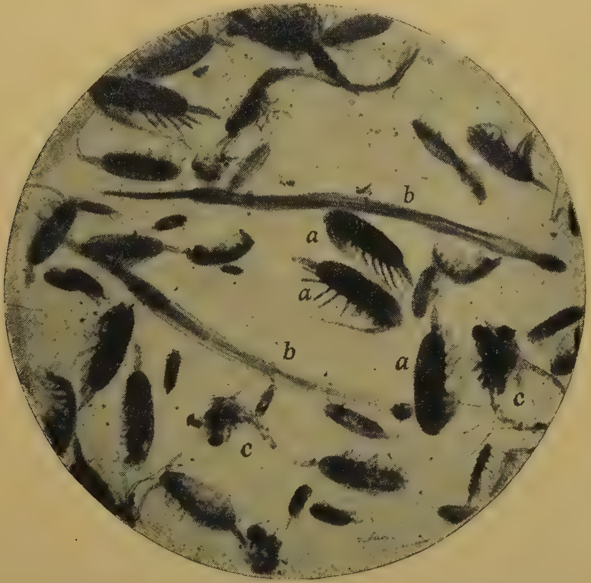

FIG. 3.—A sample of animal plankton (zooplankton) magnified about six times (i.e. × 6 diam.), showing among other forms: (a) *Calanus*, the principal food of the herring, (b) the arrow-worm *Sagitta*, and (c) young planktonic stages of the crab.

under which they live, the flow of ocean currents, the chemistry of the sea and the varying nature of the sea bottom and its life. The aim of all this work, set before it by the International Council, is "*the rational exploitation of the sea.*"

This science of marine ecology is working to provide answers to such questions as the following: Why do fisheries fluctuate—fish sometimes being plentiful, sometimes scarce? Why do fish vary in quality; sometimes there being a shortage of the size most desired by the trade? Can forecasts be made of the future state of a fishery? Can science provide the means to enable fishermen to locate the fish more easily with a saving in time, labour and fuel? Is this or that area being over-fished, and if so what is the best remedy?

Some of these questions have already been answered in part, but progress cannot be rapid. On the land we can watch the harvest in the making; but in the sea all is hidden from us beneath the surface. Everything the scientist must find out about the fish, and the conditions under which they live, he must grope for in an unseen world; and the sea is a big place. He lets down his instruments on ropes and wires—some to take the sea's varying temperature and to collect samples of the water from different regions and depths for chemical analysis, others to measure the amount of light reaching different levels, and others again to record the speed and direction of ocean currents. He sweeps the waters with all kinds of nets to sample the small forms of life which we have seen are so important to the fish. Building up a picture of life in the sea is like putting together a huge jigsaw puzzle made up of tiny pieces, when not only have we a very imperfect idea of the kind of picture which will emerge, but all the pieces to be fitted together are not on the table before us, but somewhere under the table in the darkness. It is a fascinating pursuit, but full of disappointments. Some bits of the puzzle can only be found during a short period of the year; before they can be picked up stormy weather may intervene, so that the instruments cannot be used, and we must wait a whole year before another chance will come. Experiment and observation must be made in the open sea as well as in the shelter of the laboratory.

Yes, progress is slow; but this picture of life in the sea is growing and becoming clearer and clearer. The pioneers have already built up a great body of knowledge, and every year this information and its value will increase.

Early Work.

Marine ecology, this study of life in the sea in terms of measurable relationships, is a very young science. It is a modern development of Oceanography, which began very little earlier as a general descriptive science of the sea. This is not the place to write its history; nevertheless the briefest outline of the more important phases of its development may not be out of place, if for no other reason than that of showing how the work described in this volume is dependent upon the discoveries made by the pioneers of the past and also by our contemporaries working in other institutions. Those who are familiar with this history can skip and pass at once to the next subsection, which deals with the beginnings of our work at Hull.

There are still nearly thirty years to go before we can celebrate the centenary of the real birth of Oceanography—the sailing of the *Challenger* Expedition in 1872. Before that time there were only very sketchy ideas of the physical conditions in the sea and of its life. It is just a hundred years ago since Johannes Müller first used what we have come to call the tow-net—a small conical net of fine silk gauze or muslin with a little collecting jar at the end of it. By towing it behind a boat he was the first to reveal this teeming world of tiny plants and animals which we call the plankton. About this time, too, Edward Forbes, in addition to being the first naturalist in this country to follow Müller in the use of the tow-net, was carrying out pioneer dredging in the coastal waters, and declaring that it would be impossible for life to exist below some 300 fathoms. He believed there was a great region in the depths entirely devoid of life. This was the generally accepted view until the late 'sixties, when Wyville Thomson and Carpenter on the *Lightning* and *Porcupine* expeditions dredged to depths of over a thousand fathoms and showed, as far as they went, a wealth of life new to science on the ocean floor. It was their exciting discoveries together with the interest being taken in the new projects of submarine cables which led to the dispatch of H.M.S. *Challenger*, under the directorship of Sir Wyville Thomson, on its epoch-making five years' voyage to explore all the oceans of the world.

The end of the last century and the beginning of this was the descriptive period of marine natural history. The results of the *Challenger* Expedition filled more than fifty massive volumes, and a number of other important series of reports were published as other nations followed in sending similar expeditions to explore the depths of the seas and describe their life. The Prince of Monaco was one of the pioneers and patrons of this new science. This period, too, saw the founding of the famous marine stations, the first at Naples, then Plymouth in this country, and Wood's Hole in America ; in these laboratories researches into the structure, development, life and habits of marine creatures of all kinds have been continued to the present day.

The eighteen-nineties saw the birth of true ecology when the German naturalist, Victor Hensen, began his studies. It was he who first introduced the term *plankton*. He and his fellow workers at Kiel developed their elaborate painstaking process of estimating the actual numbers of these little specks of life in known quantities of water from different parts of the sea. They attempted to calculate the total productivity of the sea under different conditions. They showed that there were sometimes millions of these living forms in one cubic yard of water. At this time, too, Cleve, the Swedish oceanographer, produced his charts of plankton distribution, showing that different ocean currents carried with them different communities of life.

Then came the investigations of the International Council already referred to—a unique and splendid example of what may be achieved by wide international co-operation. From 1902 to 1908 the research ships of the different nations, each being allotted different parts of the sea, undertook quarterly cruises to investigate the varying abundance of the plankton at many different points scattered over the whole of the waters off the north-west of Europe. Elaborate records were kept of the landings of different kinds of fish at the different ports, and a staff of fish measurers was employed to collect a mass of information as to the sizes of different fishes in different areas. The migrations of fish were discovered by attaching little numbered labels to them, letting them go and offering rewards for information about their recapture. The fish were measured before being released and measured again when recaught, so by this method not only could their movements be studied, but their rates of growth in different parts of the sea. Young fish were marked and transplanted from one part of the sea to another which was richer in food, and their increased growth compared with that of similar fish left behind—the first experiment in the farming of the sea. The spawning grounds were charted, and the drift of the baby fish followed as they hatched out to feed on the plankton and to be carried along by the currents to the regions where they settle down and begin to grow up. In the early days of the century these pioneer fishery investigations were developing in a number of countries, particularly under the leadership of C. G. J. Petersen in Denmark, Johan Hjort in Norway, and Walter Garstang in this country. At the same time our knowledge of the changing areas of warmer and colder waters, of more salt or less salt water, was advancing with the working out of the complex systems of ocean currents. Petersen began his work of estimating the quantities of animal life on the sea bed by using a special "grab," which could bring up measured samples of the sand or gravel, together with all the animals in it. All these investigations have been continued to the present day. The great body of knowledge that has been built up about the lives of fish, such as the plaice, cod, haddock, herring and hake, cannot be summarized here, and we can but mention the amount of work that has been done on the subject of mesh regulation and the problem of over-fishing generally.[1] The object here is just to place the investigations about to be described against the general background of work that has been developing in this science of the sea.

Our research deals essentially with the plankton, and a little more must be said about the course of plankton investigations in particular. The earlier work was descriptive; the quarterly cruises made under the International Council told us what kinds of planktonic animals and plants were usually found in different areas in the different seasons. Many special plankton cruises have been made in relation to fisheries work, charting the distribution of the plankton in great detail by using Hensen's methods of estimating the actual numbers found in a definite body of water filtered by nets of a known size. The research ship steams backwards and forwards across the sea on definite lines, stopping at intervals, perhaps 20 miles apart, to take its samples.

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[1] See the recent books: 'The Overfishing Problem,' by E. S. Russell (1942), and 'The Fish Gate,' by Michael Graham (1943).

Many such cruises have also been made to estimate the quantities and distribution of fish eggs and young fish. The discovery that nearly all bottom-living fish lay floating eggs was one of the first economic contributions of marine research. Towards the end of last century, when the trawl was increasing in size, there was an outcry by certain sections of the industry demanding a limit to the size of the trawl, which they thought must be destroying the spawn on the sea bed. There was a Royal Commission to investigate the matter. But in the meantime the tow-net had given the answer: G. O. Sars, the great Norwegian naturalist, had shown that the cod and other bottom-living fish lay floating eggs, so that these fears, like the eggs, were groundless. The eggs float as little spheres, hatching out into baby fish, which live for an important period of their life as part of the plankton. The herring, which spends so much of its adult life feeding on plankton near the surface, is curiously an exception in laying its eggs on the sea bed, although its young come up into the plankton as soon as they are hatched.

Another series of investigations was begun in 1907 by the late Sir William Herdman. Week after week, year by year, he had tow-nettings taken across the bay at Port Erin, Isle of Man, to study the seasonal changes in the plankton, and to compare the amount found in one year with that found in another. They were continued until 1920, and gave a great deal of information about the succession of different kinds of plankton throughout the year. The plankton is not only made up of those forms which spend all their life in this drifting, floating state; in addition there are numbers of young forms, *larvae* as they are called by scientists, of animals such as starfish, sea urchins, worms and shellfish, which live on the sea bottom. They send up these young floating larvae to spread their kind far and wide over the sea.[1] Such investigations as these show how at various seasons larvae of different kinds come into the plankton and make up an important part of it.

This was the trend of plankton research up to the last war—mainly a descriptive phase. Then came a new line of investigation at the coastal laboratories, as at Plymouth and Millport in this country, into the physical and chemical conditions of the sea that control the plankton production. This revealed the part played by sunlight and the all-important salts, the phosphates and nitrates, in the growth of the little plants, and the effect of plankton animals keeping them in check by grazing them down. This work was making great advances when it was interrupted by the present conflict.

During this inter-war period, at the other end of the world, began the *Discovery* investigations carried out by the Colonial Office on behalf of the Falkland Islands Government; they relate to the same fundamental problems as those studied by the International Council, but are concerned directly with the ecological factors underlying the great whale fisheries in Antarctic waters. It was whilst serving on the first of this series of *Discovery* Expeditions under the leadership of Dr. Stanley Kemp, F.R.S., that I experimented with the first continuous plankton recorder. The work presently to be described owes much to his kind encouragement in those early days, when the machine was being developed and so often went wrong.

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[1] Some of these are shown in Fig. 14, p. xli.

THE BEGINNING OF WORK AT HULL AND ITS FIRST PRACTICAL OUTCOME.

We must now come to what this volume is about. Our work at Hull is at present concerned with the plankton and its influence on the fisheries. Its most immediate application is to the herring side of the industry, but we believe in time it will also contribute to a better understanding of trawl fishery problems. It is the direct outcome of work begun when I was serving on the scientific staff of the Fisheries Laboratory of the Ministry of Agriculture and Fisheries at Lowestoft under the directorship of Dr. E. S. Russell. I like to feel that it is still part of that work. As stated in the Preface, our researches are carried out in close co-operation with the Fishery Departments of both the Ministry and the Scottish Home Department; they are not intended to be isolated investigations, but to fit in with their research programmes and link up with the work of the International Council.

At Lowestoft in 1921 I began to work on the ecology of the herring—its food and its relations to the plankton in general. It was a poor autumn herring season that year; the fish were not being taken in their usual quantities. When out on a herring drifter I took plankton samples with a tow-net and found the water was thick with one of the small plants—one known to science by the long name *Rhizosolenia*, which I must mention because I want to refer to it again and it has no other name. It is shown in Fig. 2. So abundant was it that the meshes of the fine silk net were clogged with it. The skipper said they called this water "weedy water," or sometimes "Dutchman's baccy juice," because the nets came up slimy and brown and he said they were unlikely to catch fish in it.

I then started experimenting with a little instrument I have called the plankton indicator, a little torpedo-shaped device, hollow, and open at each end to allow the water to flow through it. It was designed to be taken down by a weighted rope when towed behind a drifter. Before being thrown out, a small gauze disc was placed across the water tunnel so that it sieved out the plankton as it was towed along. Fishermen were asked to use this instrument to take a sample of the plankton where they fished, and then to wrap up the disc after they had used it and drop it into a tin containing the preservative formalin. Then, after they had shot their nets and hauled them again, they filled in a printed label giving the date, position, and the number of herring caught. The idea was to get a series of plankton samples together with records of the catch of fish, so as to obtain definite experimental evidence as to whether the fisherman's belief in the poor catches to be expected in this so-called "weedy water" was actually based on fact or not. It was first tried out in the autumn of 1922, but only twelve records were obtained with it that season. The number was very low, but the results were highly significant. In six of those twelve hauls the indicator discs were quite clean; in the other six they were coloured a distinct green by the presence of quantities of the tiny plants, this time not *Rhizosolenia*, but another little plant called *Phaeocystis*. The six herring catches corresponding to the clean discs were 15, 15, 17, 30, 30 and 45 crans (a cran is a measure for roughly a thousand fish). The catches corresponding to the six green discs were $\frac{1}{2}$, 2, 3, 3, 3 and 6 crans. We see that all the catches which were in *clear* water were from 15 to 45 crans, with an *average of 25*, whereas none of the catches with a green disc was greater than *6* crans, with an *average of 3*. The odds against such a clear-cut result being just due to chance are millions to one.

It was not until I had been working for some little time on these lines that I came across the very interesting observations which Mr. Pearcey made in 1884 and recorded in a paper in the 'Proceedings of the Royal Physical Society of Edinburgh' for 1885. He made a voyage in one of the old sailing luggers from Leith round the Shetland Isles, taking with him a tow-net. He, too, was studying the plankton in relation to the herring, sixty years ago, and it is surprising that his results were not better known to fishery investigators. He came across dense zones of the little plants, so thick, he writes, "that little heaps of the algae were formed on the deck as it dropped from the nets," and in each of these areas he caught hardly any herring. In the clear regions between, the herring catches were high.

It seemed likely that the dense patches of plant-plankton, produced in the autumn in the southern North Sea, might play an important part in the success or failure of the East Anglian herring fisheries, which extend from the end of September to the beginning of December. With Mr. Savage, of the Ministry of Fisheries, I therefore started in 1922 a series of annual cruises in the research ship *George Bligh* to chart the extent of such patches during each autumn fishery. When I left to join the first of the present series of *Discovery* expeditions to investigate the biology of the whales in the Antarctic, Mr. Savage continued these autumn cruises. The patches were shown to vary enormously in both size and position from year to year. Sometimes there were patches of *Rhizosolenia*, sometimes of *Phaeocystis*, and at other times yet another tiny plant, *Biddulphia*, or sometimes areas of *Rhizosolenia* and *Biddulphia* partly mixing one with the other. Considerable evidence was obtained that when these patches occurred near to the main shoaling grounds the arrival of the herring there was delayed, or sometimes the fish were deflected from the normal grounds.

On returning from the Antarctic I was appointed Professor of Zoology at our new University College of Hull when it opened in 1928. From the beginning it was intended that a Fishery Research Department should be developed, and in 1931 my Department was enlarged to that of Zoology and Oceanography. The new laboratories were opened by the late Sir John D. Marsden, Bart., then President of the British Trawlers' Federation. The appointment of the research staff (see p. iv) and the financing of the Department are described in 'Bulletin' No. 1.

We had two programmes of work. The first was completed in 1934 and described in reports by Drs. Lucas, Henderson and Fraser and myself, published in 1936 in the 'Journal of the Marine Biological Association,' vol. xxi, pp. 147–291; the second and larger programme is the subject of the present series of 'Bulletins.' The first has a distinct bearing upon the second, so that a short account of it must be given; all details will be found in the reports just referred to.

First I was anxious to try out again the small plankton indicator which I had begun to use at Lowestoft. In addition to its trial in the autumn fishery, when the unfavourable *plant* plankton is common, I had made fairly extensive trials of it in the summer Shields fishery in an attempt to establish whether or not any relation could be found between the catches of the feeding shoals and the abundance of the *animal plankton* which was their food. Plankton is patchy; it is known often to vary enormously in quantity and kind at points even quite short distances apart. No relation was then established, but I realized that the instrument, while efficient in the capture of the plant plankton, was by no means so well adapted to the collection of the animal forms. Very often the weight failed to take it down properly below the surface. We therefore started the experiments all over again with a newly-designed indicator on the lines of a paravane, fitted with diving planes and stabilizing tail, so that it automatically dived below the surface and took up a position at about the depth that the herring nets are used. The instrument is shown in Fig. 4 (see also p. 240). The experiments were carried out on a large scale; we received the willing help of 32 drifter skippers, and in

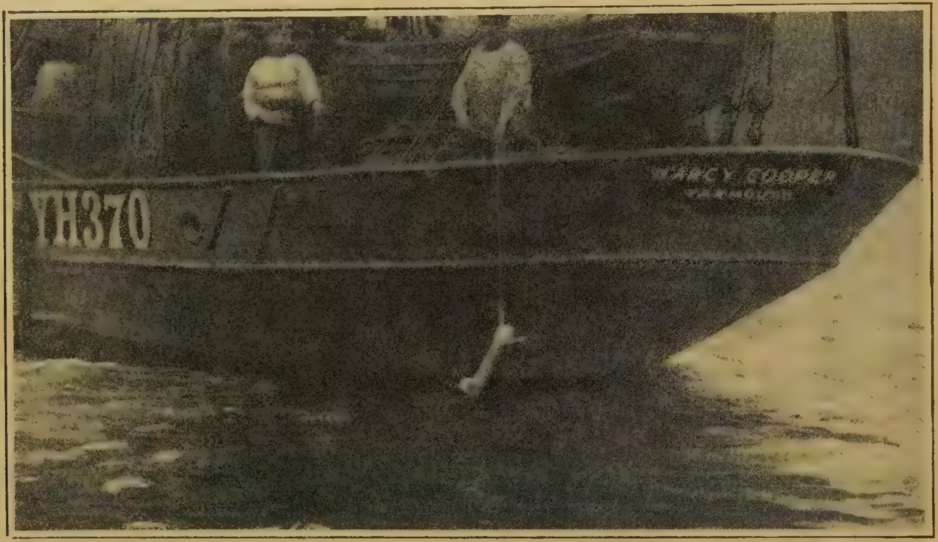

FIG. 4.—The Plankton Indicator in use on a drifter; it is normally used without stopping the vessel (see also more detailed illustration on p. 240).

addition officers of the Royal Navy in command of Fishery Protection gunboats and commanding officers of fishery cruisers of the Fishery Board for Scotland kindly took records alongside drifters fishing.

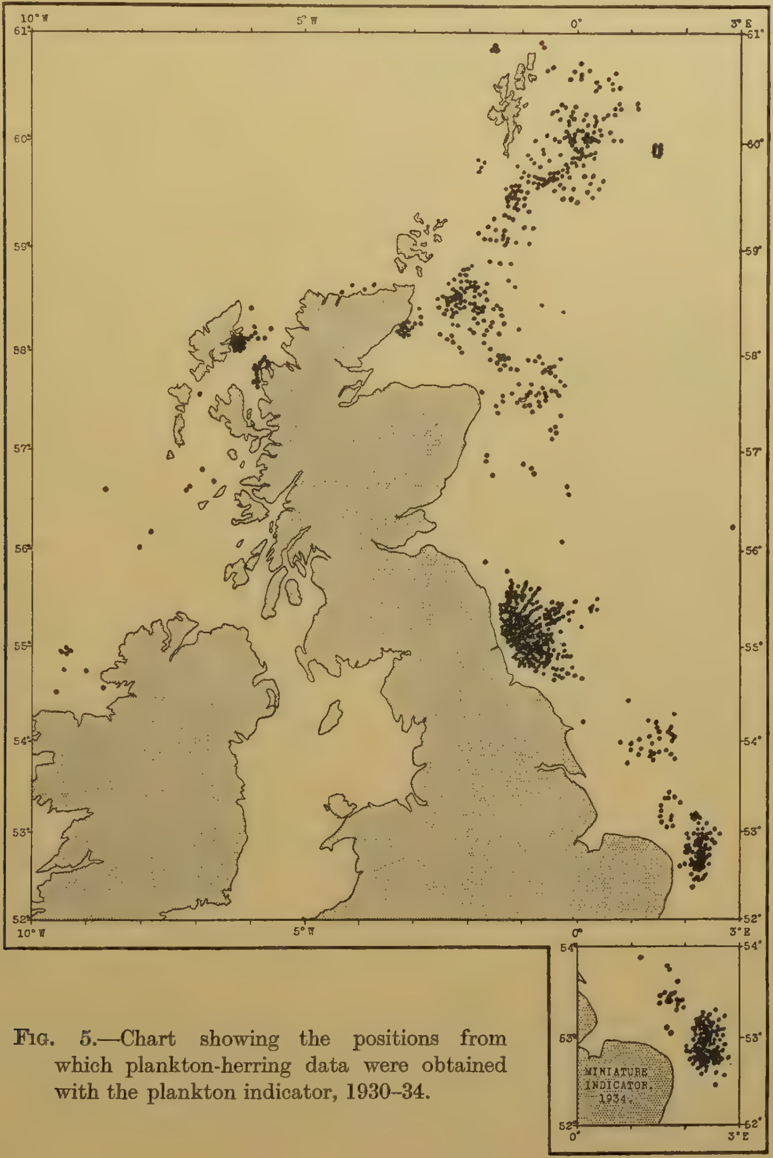

Fig. 5.—Chart showing the positions from which plankton-herring data were obtained with the plankton indicator, 1930–34.

The same system of providing drifter skippers with labels and tins of formalin, as described for the earlier experiment, was adopted. They were asked to use the instrument just before they reached the position at which they intended to shoot their nets, and to tow it for one mile up to their position for fishing. Over fourteen hundred records were obtained : records of catches of fish with corresponding samples of plankton for analysis. Fig. 5 shows the positions in which they were taken. We divided the areas of fishing into regions separated by degrees of latitude and dealt with the samples from each region in half-monthly periods. We now examined the samples to see if there was any connection between the numbers of herring caught and the numbers of the special little animals, which they prefer for food, found in the sea at the same time and place. Earlier work had shown that the herring's favourite food is the little shrimp-like animal called *Calanus* (see Fig. 3). Having analysed the plankton samples we wrote down the number of Calanus found in each and then arranged them in ascending order from the lowest to the highest numbers, and we put them down in two columns, that on the left being half the number of samples and having those with the *lower* Calanus numbers, that on the right being the other half, having the *higher* Calanus numbers. Then in columns against the Calanus figures we wrote down the corresponding quantities of herring caught. Thus we can total up the number of herring caught in the regions of *poor* Calanus water and compare it with the total caught in the *richer* Calanus water. This may appear a little complicated, but it is most important that the fisherman should understand what we have done ; his future benefit, we believe, will depend upon his understanding this relationship. An example will, I think, make it clear. The following figures are for the Eastern Scottish Area, latitude 59°–60° N., for the second half of July, 1932 :

	In poorer Calanus water.		In richer Calanus water.	
	Calanus numbers.	Herring (in crans).	Calanus numbers.	Herring (in crans).
	1	0	120	36
	1	24	125	47
	20	20	165	2
	25	4¾	180	9½
	40	0	204	61
	42	4½	245	37½
	68	¾	280	63
	88	72	330	59½
	96	30	332	10¾
	101	1	480	19
	105	0	1420	0
Totals	587	157	3881	345¼
Averages	53	14¼	353	31½

We see that while some good herring catches were made in the poorer Calanus water, and some poor catches were made in the richer Calanus water, the *total catch* in the richer Calanus water was *more than double* that in the poorer water: an average catch of 31½ crans as against 14¼ crans. This example is shown in diagram form in Fig. 6. For the eastern Scottish fisheries, from the Shetlands southwards, the catches in the richer Calanus water exceeded those in the poorer Calanus water for fourteen out of eighteen such periods of experiment. The increased catch in the richer Calanus water was usually very considerable.

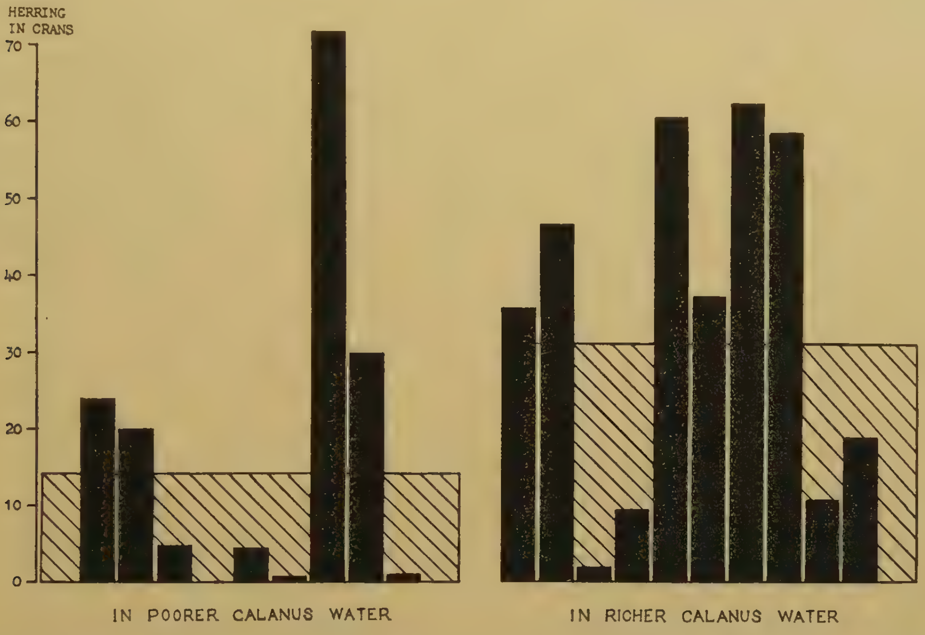

Fig. 6.—A graphical comparison of the individual herring catches (black columns) and the average catches (shaded blocks) in the poorer and richer *Calanus* water off the north-east of Scotland (59°–60° N.) in the second half of July, 1932.

We then wanted to find out what would be the advantage if a drifter skipper actually used the indicator to guide him towards the richer feeding-grounds. In our example the total catch of herring during the period was 502¼ crans (157 plus 345¼): that is what the skipper got by fishing sometimes in poorer and sometimes in richer Calanus water. If he used the indicator to test the water as he steamed out from port, taking samples every few miles and fishing at the place where he got the most Calanus, he should easily have come into water that was distinctly above the average Calanus content *each* time he fished, instead of only sometimes. Now, if all the catches had been in the richer Calanus water instead of only half, he should have caught 345¼ crans twice over, which comes to 690½ crans, instead of 345¼ in rich and 157 in poor water, which was only 502¼ crans; he would have got a gain of 188¼ crans, or 37½ per cent. This is of course only an *estimated* gain, and reliance must not be placed on just one such example; but if we take the whole series of eighteen periods, including the four in which the catch of herrings was actually less in the richer Calanus water, we get an average gain for the whole of the eastern Scottish fisheries of 24½ per cent. This means that by a regular use of the instrument (although it would fail on occasions because of irregularities in the movements of the fish, which are sometimes swimming in search of food, and sometimes collecting for spawning), the fishermen would increase their average yield per boat by nearly 25 per cent. In the Shields fisheries the results were not so good, but still they gave an average gain of 12·7 per cent. or 21·2 per cent. if we omit the results of 1931, which were exceptional for reasons which we now understand.[1] We also had abundant evidence to confirm the opposite relation between the herring and dense zones of plant plankton, which would give the fishermen a clear indication by a green coloured disc; they should always steer clear of such water. Without the indicator they do not usually know they are in this "weedy water" until they have hauled their nets and found them all slimy—by that time their night's fishing has been wasted. The instrument has thus become a commercial possibility. A green indication is seen at a glance (Fig. 7); but to see the Calanus the fisherman drops the disc into a little frame carrying a lens powerful enough to give a good magnification (Fig. 8). He cannot mistake Calanus for anything else: photographs and discs with preserved Calanus on them are provided for comparison; he soon learns to distinguish it (Fig. 9).

Several of the more progressive skippers have taken it up and been very pleased with the results. As examples of just how it works in practice I will quote from two accounts written by drifter skippers and published in *The Fishing News* (24th February and 16th June, 1934); the first is by Mr. Ronald Balls, master of the S.D. *Violet and Rose*, YH757:

> "Calanus is very easily recognized on the disc, and any boats that could do most of their fishing in water containing it could certainly expect a considerable increase in their catches. . . .
>
> "First of all, it is most important that the Indicator should be used as consistently as possible over at least a whole summer season for a real test of its usefulness, because, although there are cases where when good feed is found an excellent catch results, this is not always the case, and occasionally the opposite happens. It is only by continuous use over a period of weeks that the benefits of the instrument become apparent.
>
> "Nevertheless, I have found during the summer that at any time when a small belt of Calanus has been found, with the surrounding waters devoid of feed, a superior catch has always been the result of shooting in the feed. Naturally, one cannot expect this to happen very often, and when Calanus is very widespread choice of position for fishing is unnecessary unless, as sometimes happens, there are also patches of unfavourable plankton about, when the Indicator can be used in its other capacity.
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> "As an illustration of this I can quote from my own experience on Monday, July 10, of last year. On this day, steering north by east from Rattray Point, we found Calanus fairly

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[1] Those specially interested will find these reasons given on p. xl of this "Explanation" in an account of the work in 'Bulletin' No. 5.

Fig. 7.—Examining the disc for a green (plant plankton) indication.

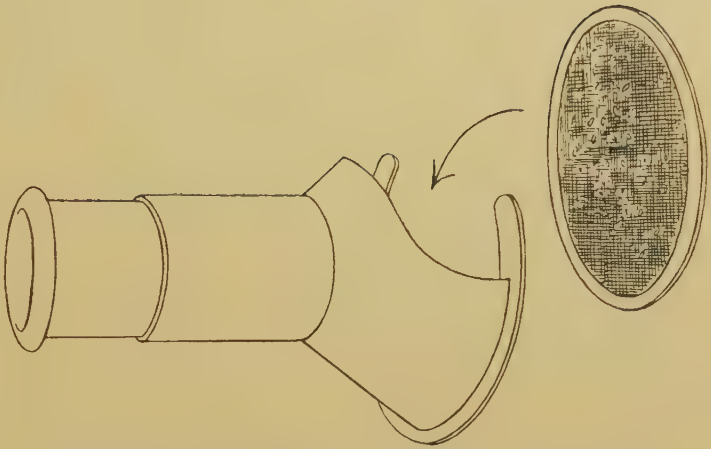

Fig. 8.—The lens holder used for viewing the disc for *Calanus* indications; it is simply held up to the light.

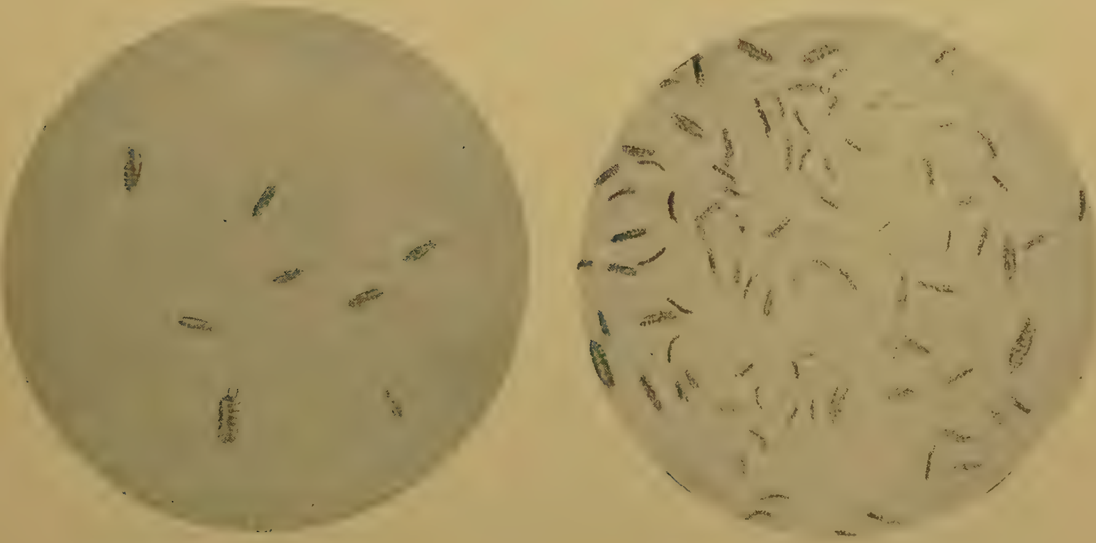

Fig. 9.—Poor and good *Calanus* discs as seen through the examination lens.

good from 30 miles onward to 50 miles, but although each disc we towed was seemingly good enough to shoot on, I noticed that every one was clogged with a fine jelly-like substance. Continuing on our course, at 54 miles we obtained a good disc of Calanus, which was also quite free from the jelly ; in fact, the remarkable liveliness of the Calanus here was noticeable after their lifeless condition when amongst the jelly on the earlier discs.

" Thus, although we had found good feed for over 20 miles, there was also the unfavourable organism present until we were 54 miles from Rattray. We shot exactly where we had towed this good disc, and our catch of 70 crans next morning was well above the average at Peterhead or Fraserburgh.

" I have also found that when there is no Calanus about but only wide patches of weedy or unfavourable water, the same procedure of steaming until clean water is found usually has a beneficial result. . . .

" From May 1 to July 30 we shot 69 times—40 shots were in water with little or no Calanus, and the average catch for these was 3 crans ; 29 shots were in water containing good or fairly good Calanus, and the average for these 29 shots was 9·5 crans. Thus, when Calanus was present there was an increase of 216% in the average catch."

The second account is by Mr. H. K. George, master of the S.D. *Ocean Spray*, YH264 :

" I feel sure that other skippers amongst your readers will be interested in hearing of further practical results obtained with the Indicator, as if properly worked and studied it will greatly assist a skipper in finding the best fishing grounds in the spring and summer fishing. As examples I will quote two instances which stand out vividly in my mind.

" Herrings were very scarce and dear at Shields on this particular day, and the only boat to have any was the motor boat *Twilight* with 12 crans from N.E. by N. 20 miles, so that was where we started for that day. After we had steamed 8 miles I put the Indicator over and pulled it up every mile until we were 13 miles without seeing the slightest signs of Calanus.

" Between 13 and 14 miles there were a few on the disc ; from 14 to 15 miles it was a very good disc ; from 15 to 16 miles it was only moderate again, and from then on to where the *Twilight* was shooting her nets at 20 miles there was nothing on the disc, so we steamed back to where we found the Calanus, and we found it again.

" We shot our nets and got 16 crans of herrings, which was a good night's work, and not one of the other boats got any, they all being three miles and more to the north of us.

" The next instance was one day we had 40 crans from 22 miles E.N.E. and steaming off that day I put the Indicator over and the best disc I got was between 17 and 18 miles, but I carried on the 22 miles and could not find any Calanus, so I steamed back to where I got the good disc and found it again.

" The same thing happened as before, and with that and many other instances when it happened it gave me complete confidence, though I don't pretend to think it is infallible, as at times we have found feed and got very few herrings, and at others we have not found any feed and yet we have got a few herrings, though not many.

" I also noticed that the week when herrings were plentiful at Shields the sea where the herrings were was full of Calanus, but it didn't last long in so widespread a nature, neither did the herrings. I have had several chats with other skippers who I know take a great interest in this work, and I am sure we were unanimous on the point that the skipper who has an Indicator and takes interest in it will be streets ahead of them who just trust to pot luck.

" Some of the older skippers don't believe in it though I think in a very short time they will have to admit."

Confirmation of our results comes also from Iceland, where Mr. A. Fridriksson tried out one of our indicators with success and published his results in 1935.[1]

In spite of these favourable reports and our published statistics, it had not come into general use by the beginning of the war. No doubt it will in time—but it is not easy to convince a skipper who does not keep careful records that it is really benefiting him. It does *not* work *every time*. In the period tabulated, which is typical, we see, as already pointed out, a number of good herring catches in the poor Calanus water and a number of poor catches in the good Calanus water ; it is only when we take the *average* of a number of occasions that the benefit is realized. In our example we see that in the very best Calanus water no herring were taken at all. A skipper getting such a result might well say, " This is a fraud ! Its no use at all," or more likely something stronger, and give it up. Again, if he realizes that he *has* increased his catch on an average by some 25 per cent. since he took up using the indicator, is he convinced that this is due to the extra trouble he has taken in using it and not just luck ? Often he will get a spell of good luck and a spell of bad luck ; and the use of the indicator does entail a certain amount of extra trouble. It is easier to trust to luck than to follow science ; but there is no doubt from our published figures which really pays. It will take time and a good deal of instruction to get the indicator into regular use. The development of our second and larger programme took up all our time and energy, so that we were not able to do this educational work in the use of the indicator ; it is a task we must undertake after the war.

The Plankton Recorder Survey.

The second and, ultimately we believe, more important line of work which has occupied us and which forms the subject of this volume has been the study of the large scale changes in the abundance and distribution of the plankton over wide stretches of the North Sea month by month and year by year. The plankton varies from season to season and in no two years is it alike. The strength and course of ocean currents alter, as do the climatic and water conditions which may favour or discourage the growth and multiplication of this or that kind of little animal or plant.

We are studying these major planktonic changes over wide areas, much as the weather expert studies the changes in the distribution of centres of high and low pressure in the atmosphere with a view to forecasting ; but we are dealing with changing centres of *high and low production of plankton*—and of plankton of many different kinds. We are building up series of monthly charts, and just as weather maps could never be constructed from observations made at a single station, even if that observatory moved about, so such charts of the *changing plankton* over wide areas cannot be constructed from the observations made by a single research ship. We are employing other means : *automatic* sampling machines which take

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[1] **'Fiskirannsoknir, Fiskifelags Islands,' iv, pp. 50 and 67. Reykjavik, 1935.**

continuous records of the plankton as they are towed at a standard depth behind steamships on regular lines across the area to be studied. We call these machines continuous plankton recorders; we will see how they work a little later. It is our intention to attempt to relate these planktonic changes, on the one hand, to the changing climatic and water conditions which are their cause, and, on the other, to the changes in the fortunes of the fisheries, both herring and trawl fisheries, which are their effect. It is hoped that, when we have advanced beyond the period of initial trial and experiment, we may gradually build up sufficient evidence of cause and effect to render forecasts possible. Apart from forecasts, an increased knowledge of the relationships of the changing plankton to the lives of fish will be a contribution towards the solution of a number of fishery problems.

How can all this benefit the fisheries? The industry is divided into its two great and distinct sections with their different interests: the trawl fisheries for bottom-living "white fish" and the drift-net fisheries for herring. Because the relation of this survey to the herring fisheries is the more direct, we will deal with that side of the industry first.

We have seen, from our indicator work already described, what a marked effect the changes in the plankton may have upon the successful fishing of individual drifters. The importance of this indicator work lies not only in its providing a practical guide to the fisherman in his daily working; by showing how the movements of the herring are closely linked up with the distribution of the plankton, it also shows how dependent the fishery as a whole must be on the changes which are taking place in the plankton over wide areas from season to season. It is for this reason that we have dealt at some length with the results of this earlier work. The main areas of food may sometimes be against the coast, and at other times many miles away from it; again, sometimes the path of the shoaling herring may be blocked by dense areas of the plant plankton, which they avoid.

In industry it is not always possible to assist the interests of the individual and at the same time benefit the industry as a whole; but here is a case in point. The drifters tend to work together in a fleet over a particular area; they work to supply a market which is largely concerned with cured fish for export, not fish for immediate consumption. It would be of great value to the fleet to know whether, during the coming month, one area on the whole was likely to be more profitable than another area. It is just such information that we expect the plankton recorder survey will in time be able to provide. It will not give detailed information for the day-to-day fishing of individual boats; that is the work of the small indicator. While one large area will on the whole be more favourable for the herring than another for some particular period, *within* that area the plankton is usually by no means evenly spread; the Calanus they seek and the plant plankton they avoid may differ markedly in quantity at points only a few miles apart. *Both recorder and indicator may be of service together.*

Now let us turn to the trawl fisheries. Do the major planktonic changes over the wider areas have an influence upon them as well? We have seen that the baby fry of the bottom-living trawl-caught fish live for a time in the upper layers of water, feeding upon the plankton ; they are themselves actually part of the plankton, drifting with the currents of the sea. An important part of fishery research, not mentioned in our earlier brief review, is recording the age of fish ; this is usually done by examining their scales, which are seen to have rings on them like those found in a cross-section of the trunk of a tree, each ring, like that in a tree, indicating a year's growth. Thus the age of cod, haddock and herring can be read ; that of the plaice is read in the same way but from the " ear stones " (otoliths), which have similar rings. The stocks of fish have been studied in detail by many different investigators so as to reveal the numbers of fish of different ages making up a population at any particular time. Such a study may show that for one kind of fish there may in one year be, let us say, far more of those which are four years old than of those which are three or five years old; this tells us that the brood hatched out four years before was far more successful than that of its preceding or following year. Work of this kind, carried out from the laboratory of the Fishery Board for Scotland at Aberdeen, revealed marked fluctuations in the haddock stock. By *fluctuations* we mean differences in the numbers from year to year ; in some years there were very many more haddock than in others. Dr. Harold Thompson found that these corresponded closely with the fluctuations in the numbers of baby haddock found in earlier years by the sampling nets of the research ship. He showed that it is now possible to forecast to the industry a year or two in advance the relative success or failure of the Scottish haddock fisheries. All the evidence pointed, as Dr. Thompson showed, to these fluctuations in the numbers of baby fish being due, not usually to differences in the quantities of eggs spawned, but to the varying mortality and survival of the young fish in the early stages of their development in different years. This varying death-rate of young fish is most likely due to there being varying quantities of *suitable planktonic food* available in different years ; there may be either differences in actual plankton production—and we know these may be very great—or else changes in its distribution brought about by changes in the strength and direction of ocean currents, such as the varying inflow of Atlantic water into the northern North Sea. It is clear that a study of the changing plankton has in this way a direct and important bearing on the trawl fisheries. This is not just an interesting fact ; it is, as we shall see, one which can be of economic value to the industry.

The tiny fish fry, both the young of the bottom-living trawl-caught fish and of the herring, are sampled by our continuous plankton recorders, as well as the plankton amongst which they are living. We have just seen how the strength of future stocks of fish can be related to the success or failure of the young broods. A report by Dr. Stubbings, dealing with the fish eggs and young fish taken in our survey, will be published in our second volume. This side of the work is only in its infancy ; but already striking differences in the number of young fish are seen in different years. Our machines are designed so that they can easily be adjusted to capture more of the young fish (and larger plankton animals), and less of the smaller forms, than they do at present. The results of these first surveys clearly show the desirability of making additional runs, with the recorders so adjusted, at just those periods of the year when a knowledge of the coming broods is particularly important to the fisheries. If the industry knows in advance that the fishing of a certain stock of fish is likely to be less profitable than usual in the coming year, *companies will have the opportunity of diverting some of their vessels to other regions until such time when they will again know in advance that this stock is improving in strength.*

Again, the animal life on the sea bed is, as we have seen, fed by the supply of plankton from above ; we may therefore expect areas of rich plankton to give rise a little later to areas of more abundant life below—food for trawl-caught fish. Changes in the distribution of these fish—and we know that their concentrations do change considerably quite apart from their normal yearly migrations—may in time be shown to follow *earlier* changes in the distribution and abundance of the plankton. Those of their irregular movements which are not linked with the changing abundance of their food will most likely be related to changes in the water conditions—changes in the extent and position of regions of oceanic or coastal waters and their mixture. Such movements of different water masses may often be shown by the changes in the areas of distribution of particular plankton animals which are characteristic of such waters. Examples of the plankton being used to show water movement will be given in our second volume.

The possibility just outlined is clearly more remote than the forecasting of the future state of a stock of fish from the numbers of fry in the plankton in preceding years—a forecast which Dr. Thompson, as we have seen, has already shown to be feasible in the case of the haddock. It is not only more remote, but it may even be undesirable under present conditions. Members of the trawling community compete for a market for fresh fish, so the industry is much more individualistic than the herring drift-net fishery ; they are in truth rival hunters, and the more enterprising are the more successful. If we should *in time* be able to announce that more trawl-fish were likely to be caught in one area than another, all the vessels might flock there and then there would be a glut on the market with falling prices. Such forecasting, if it should be possible, could only be of value to an industry working on less competitive lines. But if the movements of trawl-fish can be shown in part to be dependent upon movements of different kinds of water, then it should be possible to devise other types of indicators that would help the *individual* trawler skipper just as the plankton indicator helps the herring drifter skipper. (We must not forget that at times the cod are collecting to feed on the herring ; in time use may be made of this fact.) Such an application lies in the future and we can only slowly feel our way towards it. Our science is still very young ; new discoveries will be made which will open up fresh possibilities. We are as yet but exploring the ground.

Our friends in the industry at Hull and Grimsby may be impatient that we are carrying out our survey in the North Sea, and not proceeding at once to an investigation of the far northern waters in which they are so much more interested. There is good reason for our beginning in the North Sea. Far more is known of the water conditions of this area than is known of the far north ; we have all the records of varying saltness and temperature compiled from year to year by the International Council to refer to. Likewise there are all the weather maps and records of sunshine and rainfall available. There are also the detailed statistics of the progress of the fisheries prepared by the Ministry of Agriculture and Fisheries ; the whole of the North Sea is divided up into more than a hundred squares, and monthly charts are prepared to show the quantities of different kinds of fish landed from each square for every 100 hours' fishing. It is only in the North Sea, where we have all this other information available, that we can begin to link the changes in the plankton, as shown by such a survey, either with the fluctuations in the fisheries, or again with the basic climatic and water conditions at the back of it all. The North Sea can be used almost as a laboratory in which to work out relationships with known factors, and to establish principles which in time may come to be applied to the more distant regions about which we know at present too little. (Actually we have begun some preparatory work on the food of the arctic cod at Bear Island and Iceland, and a report on this will be published in a later volume ; but it is not yet part of our main programme.)

For the first five and a half years, from June, 1932, to the end of 1937, our plankton survey was confined to the southern part of the North Sea. This was definitely a pioneer period of trial ; it is the phase which forms the subject of this, our first volume. In 1938 the survey was extended to cover the whole of the North Sea, and in the spring of 1939 the first monthly line of observations towards Iceland was begun ; these later developments will be dealt with in our second volume.

I have been stressing the bearing of this work on the better understanding of fishery problems ; it is the purpose of this explanation to show our aims in relation to the industry. But now a note of caution. Our programme is admittedly an ambitious one. We are just at the beginning ; we have a very long way to go before the goals we are working towards can be realized. They must be approached slowly, making sure of the ground step by step ; there will be many temptations to jump to conclusions on too slender evidence. The limitations of the methods we are employing must be carefully weighed and a good deal of space in the coming ' Bulletins ' will be concerned with these. Direct economic results must not be expected quickly, although the work of the early years has already been of value in providing advance information of the areas of dense plant plankton which have such an adverse effect upon the East Anglian autumn herring fishery (see the Report of the Development Commissioners quoted on p. 8 of ' Bulletin ' No. 1). The more immediate outcome will be a better understanding of the nature of the changes taking place in the North Sea plankton community as a whole ; any steps, however, towards a better knowledge of the biology of the North Sea is a step towards ultimate economic advantage. It is with these contributions that the present volume is concerned.

Our course towards the practical ends we have suggested will not be taken alone. The short excursion into the history of our science made at the beginning of this essay was intended to show how much we are indebted in the initiation of this work to the pioneers of the past; any progress in the directions in which we are hoping to go will be made with the help of the findings of our colleagues working at kindred problems in other marine laboratories. Ours is but one line of attack among many others. It aims at providing a background to all the important investigations being carried out by other departments into the lives of the fish, their growth rates, migrations and feeding habits, into the fluctuations in their stocks and many other problems. It is not suggested that our survey replaces the need for plankton cruises by research ships for special purposes; there are many aspects of plankton research which cannot be undertaken by our methods. It is only by co-operation and the fitting together of the different lines of approach that progress can be made.

We will now pass to a brief account of the contents of the six 'Bulletins' which complete our first volume.

'BULLETIN' NO. 1.

The first paper (pp. 1–57) deals with the object, plan and methods of our survey. The structure and working of the continuous plankton recorder is described. It is stream-lined, like a torpedo, but is square in cross-section to fit the internal mechanism better; like the smaller plankton indicator already described, it is fitted with planes to make it dive below the surface and swim at a depth which may be regulated by the amount of towing cable veered out. As it is towed along it continually samples the plankton from the sea by means of a long gauze banding, which is slowly wound across a water tunnel by the action of a propeller turned by the passing water. A water tunnel opens at the very front of the machine and passes through its body to the back; the front opening is quite small, but the cross-section of the tunnel enlarges very much as it reaches the gauze, so that the filtration area is many times larger than the entrance—an arrangement which both slows down the speed of the water and allows an unobstructed flow through the gauze. The gauze banding is ruled with numbered transverse lines at 2-inch intervals. For every mile of sea through which the machine is towed fresh gauze strains off the plankton from the water and is then wound on into a storage chamber filled with preservative fluid (formalin), where it is rolled up for future examination.

The gauze banding is wound off a spool just like the film of a camera and enters and leaves the water tunnel through narrow slits; as it leaves the tunnel it is joined by another similar banding, which is wound with it on to a larger spool in the storage tank, so imprisoning the plankton between the two and preventing it spreading from one section of the roll to another. The two bandings form, in fact, a long sandwich with the plankton as the jam and it is wound up rather like

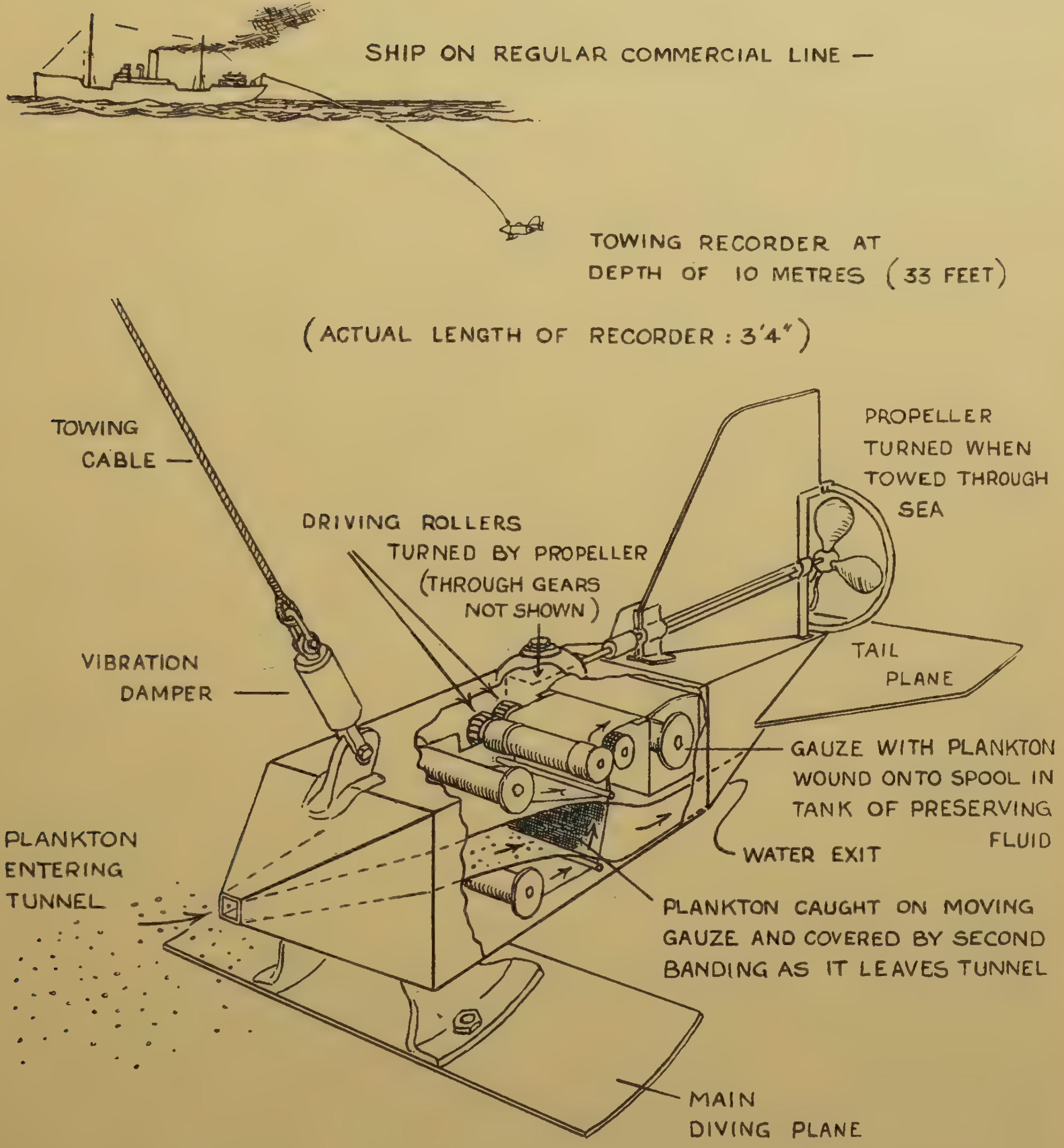
SHIP ON REGULAR COMMERCIAL LINE —
TOWING RECORDER AT DEPTH OF 10 METRES (33 FEET)
(ACTUAL LENGTH OF RECORDER : 3′4″)
TOWING CABLE —
PROPELLER TURNED WHEN TOWED THROUGH SEA
DRIVING ROLLERS TURNED BY PROPELLER (THROUGH GEARS NOT SHOWN)
VIBRATION DAMPER
TAIL PLANE
GAUZE WITH PLANKTON WOUND ONTO SPOOL IN TANK OF PRESERVING FLUID
WATER EXIT
PLANKTON ENTERING TUNNEL
PLANKTON CAUGHT ON MOVING GAUZE AND COVERED BY SECOND BANDING AS IT LEAVES TUNNEL
MAIN DIVING PLANE

Fig. 10.—A simplified diagram to show the working of the continuous plankton recorder; part of the outer casing has been cut away to show the internal mechanism. The catching gauze is actually ruled in transverse numbered divisions (not shown in drawing) each of which may represent one or more miles of sea according to the setting of the propeller blades.

a swiss roll (only double); the edges of the covering gauze are turned over so as to separate the two fabrics slightly and prevent undue pressure on the plankton. (This is an improvement made in the course of the work: in the early days of the survey the plankton suffered much from crushing.) The gauze bandings are driven on between two rollers like those of a mangle, but as they only grip the "sandwich" at the edges they do not mangle the plankton. The driving rollers turn very slowly, being themselves driven through a reduction gear from the propeller shaft. A simple diagrammatic sketch of the machine is shown here in Fig. 10, and a photograph on p. 3 of the 'Bulletin' shows that the internal mechanism may be taken out to be loaded with the gauze bandings before use, just as a camera is loaded with a new film.

At the end of a run the spool is taken out of the storage tank and mounted on a stage beneath a special traversing microscope (illustrated on pp. 32 and 34); the "swiss roll" is then unwound and the two sides of the "sandwich" separated for examination. The numbers of the different plankton animals and plants can now be counted or estimated section by section along the band, representing on a small scale the miles of sea traversed. The actual scale of working can be changed by altering the pitch of the propeller blades, which are adjustable to give a range of speed of rotation, so that each section of gauze may be made to represent one, two or more miles of sea as desired. Thus we are able to study the varying composition of the plankton mile by mile all the way across the sea—not just at isolated intervals, as by former research ship methods using tow-nets. The results can be shown as graphs representing the relative abundance of the different animals and plants along the route as shown in the example on p. 35.

The machine is made all ready for working before being taken to the ship which is to use it. The ship is provided with a special winch and davit for lowering and hauling it to and from the water. It is put out as the ship passes some definite point, usually a light-ship, on leaving one coast, and hauled up again on reaching some similar point on the opposite side of the North Sea. Throughout the survey the recorder has been towed at a standard depth of 10 metres (5½ fathoms), the cable being marked to show when this depth is reached. The machine is only just over 3 ft. in length and does not interfere at all with the speed of the ship. At the end of each run it is brought back to our laboratories for examination.

This first 'Bulletin' describes the planning of the survey and the kind help we have received from the various shipping companies co-operating in the scheme. At first, as already pointed out, the survey was confined to the southern part of the North Sea (1932–37). The recorders were run monthly along lines from Hull towards the Skagerrak (Copenhagen line), Hull to Bremen and Hull to Rotterdam, a line from London to Esbjerg being added in 1936. In 1938 the survey was enlarged to cover the whole of the North Sea (see Fig. 11), but this extended survey forms the subject of our second volume.

There is an account of the development of the recorder and the many difficulties that had to be overcome before it reached its present state of efficiency.

A great deal of the paper is taken up with discussions on such matters as the interpretation of results, the catching power of the machine, the scale of working and the limitations to the method, all of which are of too technical a nature to find a place in this general account.

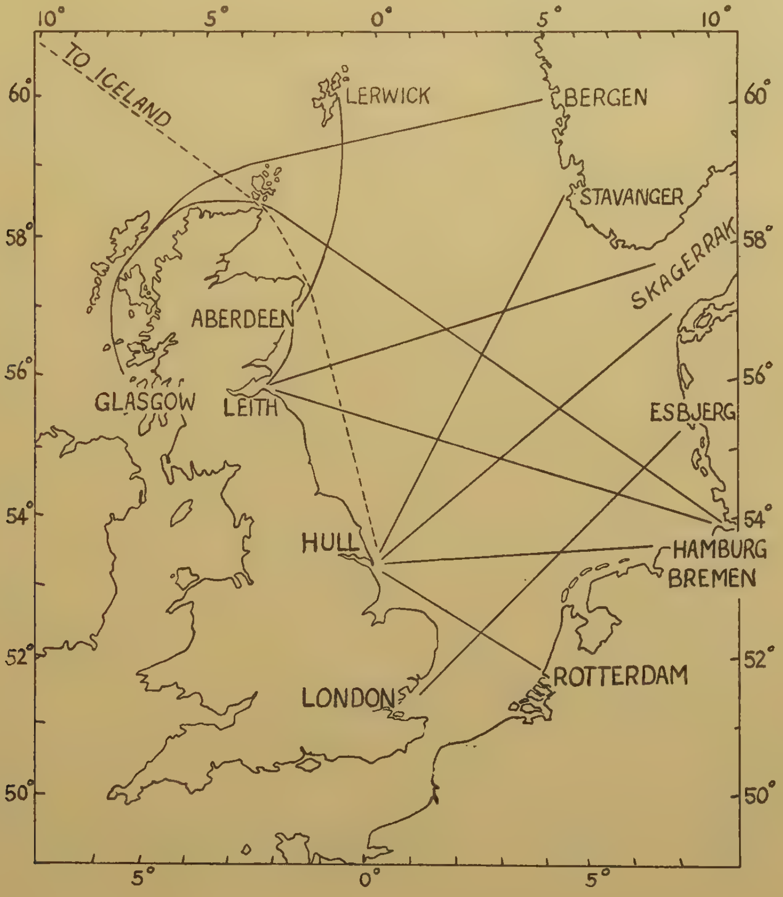
10°
5°
0°
5°
10°
TO ICELAND
LERWICK
BERGEN
60°
60°
STAVANGER
58°
58°
SKAGERRAK
ABERDEEN
56°
56°
GLASGOW
LEITH
ESBJERG
54°
54°
HULL
HAMBURG
BREMEN
52°
52°
ROTTERDAM
LONDON
50°
50°
5°
0°
5°

Fig. 11.—Chart of the extended monthly plankton recorder survey of 1938–39. The lines between Hull and the Skagerrak, Bremen and Rotterdam were begun in 1932, London to Esbjerg in 1936, and the remainder in 1938. For modifications in 1939 regarding the Stavanger and Iceland lines see ‘ Bulletin ’ No. 1, p. 56.

‘ Bulletin ’ No. 2.

The second ‘ Bulletin ’ (pp. 59–71) is a summary list giving all the particulars of dates, times, distances, weather and sea conditions, etc., for all the records made from 1932 to 1937. The total distance successfully recorded during this period was 44,246 miles.

‘BULLETIN’ No. 3.

Dr. Lucas here gives an account of the changing distribution and abundance of the little plants of the plankton (the *phytoplankton*) over the southern North Sea from June, 1932, to the end of 1937. There are a great many different kinds. Many are classed together as Diatoms ; each is a little bit of living plant matter enclosed between two thin shells of natural glass (silica), which fit together as do the bottom and lid of a pill-box. Some are indeed shaped just like a pill-box, but others are of all manner of designs, as seen in Fig. 12. Next in importance of numbers come the Dinoflagellates ; so called because they are provided with two little whip-like organs (“ flagella ”), which help to keep them up in the water. Then there is Phaeocystis—vast numbers of tiny plant cells held together in a little mass of floating jelly.

Special attention has been given to the two diatoms *Rhizosolenia styliformis* and *Biddulphia sinensis* (to give them their full names), which, as we have seen, are so important in relation to the herring fisheries in that often they densely cover large areas in the autumn and so, because herring avoid such water, delay the arrival or alter the position of the main shoals. On Plates XXII–XXXVI Dr. Lucas shows their varying abundance along the lines of our survey month by month through the different years. They are clearly most abundant in the autumn ; but see how their production varies in different years : compare, for example, the latter half of 1934 (Plate XXVII) with that of 1935 (Plate XXIX).

So as to compare more easily the relative production in different years another method of charting has been adopted. As examples let us look at Plates I and II. Here for Rhizosolenia all the records for the central line of the survey (the Hull–Bremen line) are compared together year by year. Down the side are marked twelve divisions labelled J, F, M, etc., to represent a scale of time in months, January, February, March, etc., throughout the year ; the horizontal lines represent the Bremen recorder lines, which are put in according to their dates against the scale of months. A scale of miles is given at the foot, and the vertical lines under the letters OD and B (at the top) indicate the positions of the Outer Dowsing and Borkum lightships along the recorder’s route (they lie off the Humber and German coasts respectively). The records for the different years are shown side by side under the dates (1932 to 1937) placed at the top. The quantities of Rhizosolenia recorded are shown as blacked-in graphs. It is all a little complicated at first sight, but I think worth a little trouble to understand. Once we have got the hang of the arrangement we can compare the relative abundance of this form which is so important to the herring fisheries, just as we can compare weather charts, for different years. We see how much heavier were the crops in 1935, ’36 and ’37 when compared with the three earlier years ; how much later it was in 1936 than in ’35 or ’37. In the same way the Copenhagen and Rotterdam lines are shown on other plates. Similar series are shown for *Biddulphia sinensis* and for the Dinoflagellates and Phaeocystis. As another example look at Plates XIII

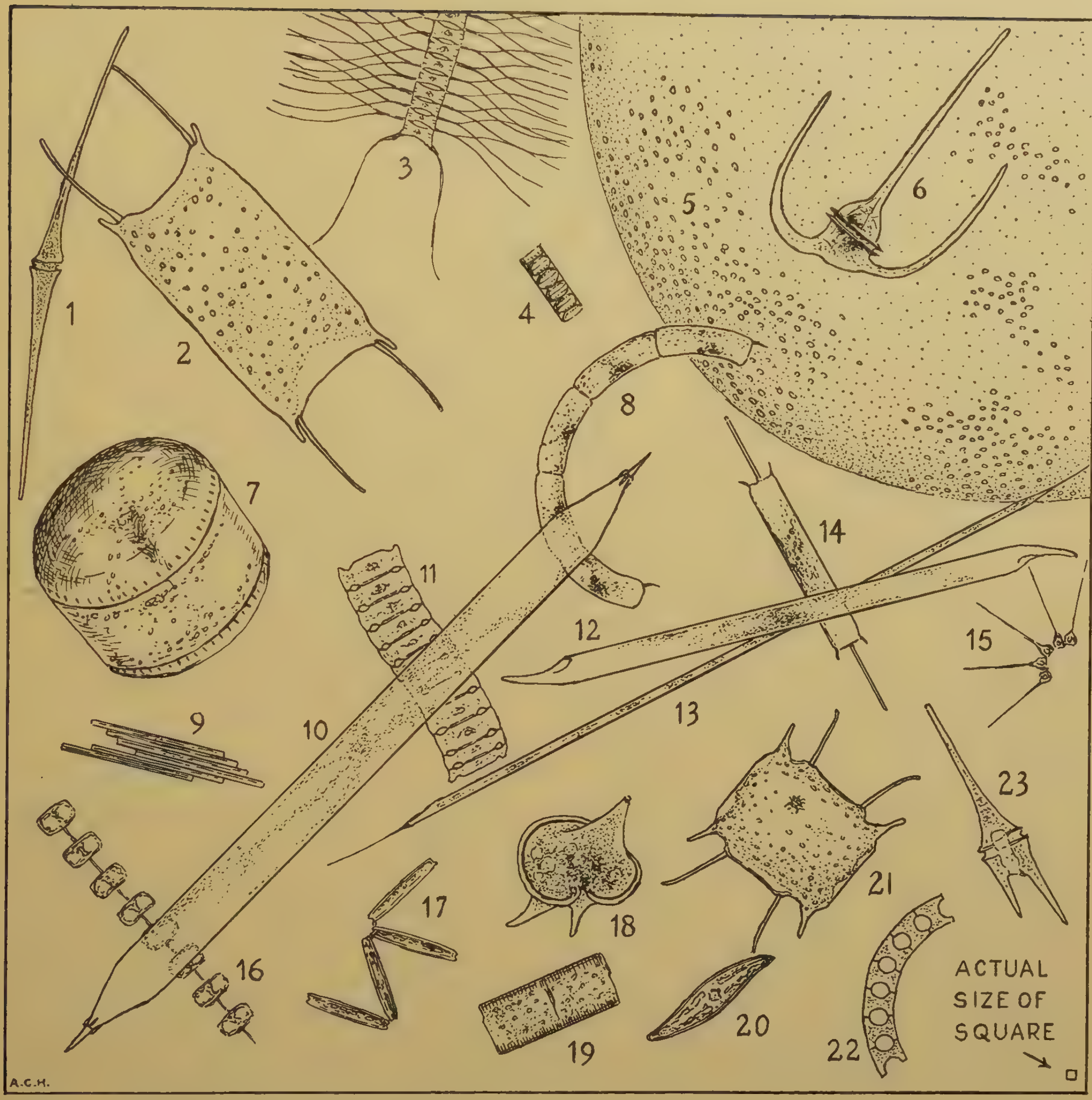

Fig. 12.—Sketches of the tiny plants of the plankton (phytoplankton) dealt with in 'Bulletin' No. 3, seen through a microscope. They are all drawn on the same scale; the actual size of the area shown is 1/20 of an inch square (see bottom right hand corner of figure). Note particularly the important diatoms *Rhizosolenia styliformis* (10) and *Biddulphia sinensis* (2), part of a Phaeocystis colony (5) and examples of Dinoflagellates (1, 6, 18, 23); all the rest are diatoms.

1. *Ceratium fusus.*
2. *Biddulphia sinensis.*
3. *Chaetoceras decipiens.*
4. *Paralia sulcata.*
5. Small part of a *Phaeocystis* colony.
6. *Ceratium tripos.*
7. *Coscinodiscus concinnus.*
8. *Rhizosolenia stolterfothii.*
9. *Bacillaria paradoxa.*
10. *Rhizosolenia styliformis.*
11. *Bellarochia malleus.*
12. *Rhizosolenia alata.*
13. *Rhizosolenia h. semispina.*
14. *Ditylium brightwelli.*
15. *Asterionella japonica.*
16. *Thalassiosira gravida.*
17. *Thalassiothrix nitzschioides.*
18. *Peridinium depressum.*
19. *Guinardia flaccida.*
20. Gyrosigma sp.
21. *Biddulphia regia.*
22. *Eucampia zoodiacus.*
23. *Ceratium furca.*

and XIV, and see the tremendous differences in the crops of Dinoflagellates on the Copenhagen line: production increasing through the years up to 1937.

The object of this " explanation " is not to describe the ' Bulletins ' in detail, but just to point out to the general reader the sort of results which have been obtained during this pioneer period. For the first time Dr. Lucas is giving us a comprehensive picture of the changes in abundance of some of the more important elements of the plant plankton over a large area month by month for a period of five and a half years. On pp. 94 and 95 he shows us the changing quantities of Rhizosolenia and Biddulphia on the Bremen line at *weekly* intervals during the more intensive survey in the autumn, which was arranged to keep a close check on the position of the patches of these plants in relation to the autumn herring fishery.

Twenty-one other kinds or groups of diatoms are dealt with in less detail; their relative abundance in different months throughout the years is shown by various symbols in the diagrammatic tables on pp. 118 to 121.

A trend towards a general increase in the plant plankton as a whole is observed over the period of years, although there are some kinds which are exceptions to this trend. In 1938 and '39, as will be recorded in our next volume, we see a return to conditions more like those at the beginning of the period. We have indications here of a long period cycle which, if confirmed by future work, may be of great importance.

'BULLETIN' NO. 4.

Here Mr. Rae and Dr. Fraser study the varying distribution and abundance of the most important single group of plankton animals, the Copepoda (meaning oar-footed animals), which are little shrimp-like creatures about the size of a pin's head. There are many different kinds, although at first sight they all look much alike. Fig. 13 shows the commoner kinds of the North Sea. *Calanus*, the important food of the herring, is one of them; it is larger than most others, being about the size of a grain of rice. It is not so abundant in the southern part of the North Sea as it is further north, and the Calanus results for this survey are being treated in a later paper, together with the 1938–39 results for the whole of the North Sea, when their significance will be better understood.

Here we see the copepods studied much as Dr. Lucas did the plants. It has long been known from the work of the International Council that there are considerable variations in the numbers of the copepods in the area from season to season. The survey sets out to give some measure of this variation. It seeks to provide answers to such questions as the following : " Is the seasonal sequence of changes in the population of the area broadly the same year after year ? How great are the ranges of fluctuation usually encountered ? Are phases of exceptionally high or low production usually only of short duration ? Do two or more species tend to fluctuate together ? Do some species tend to be more evenly

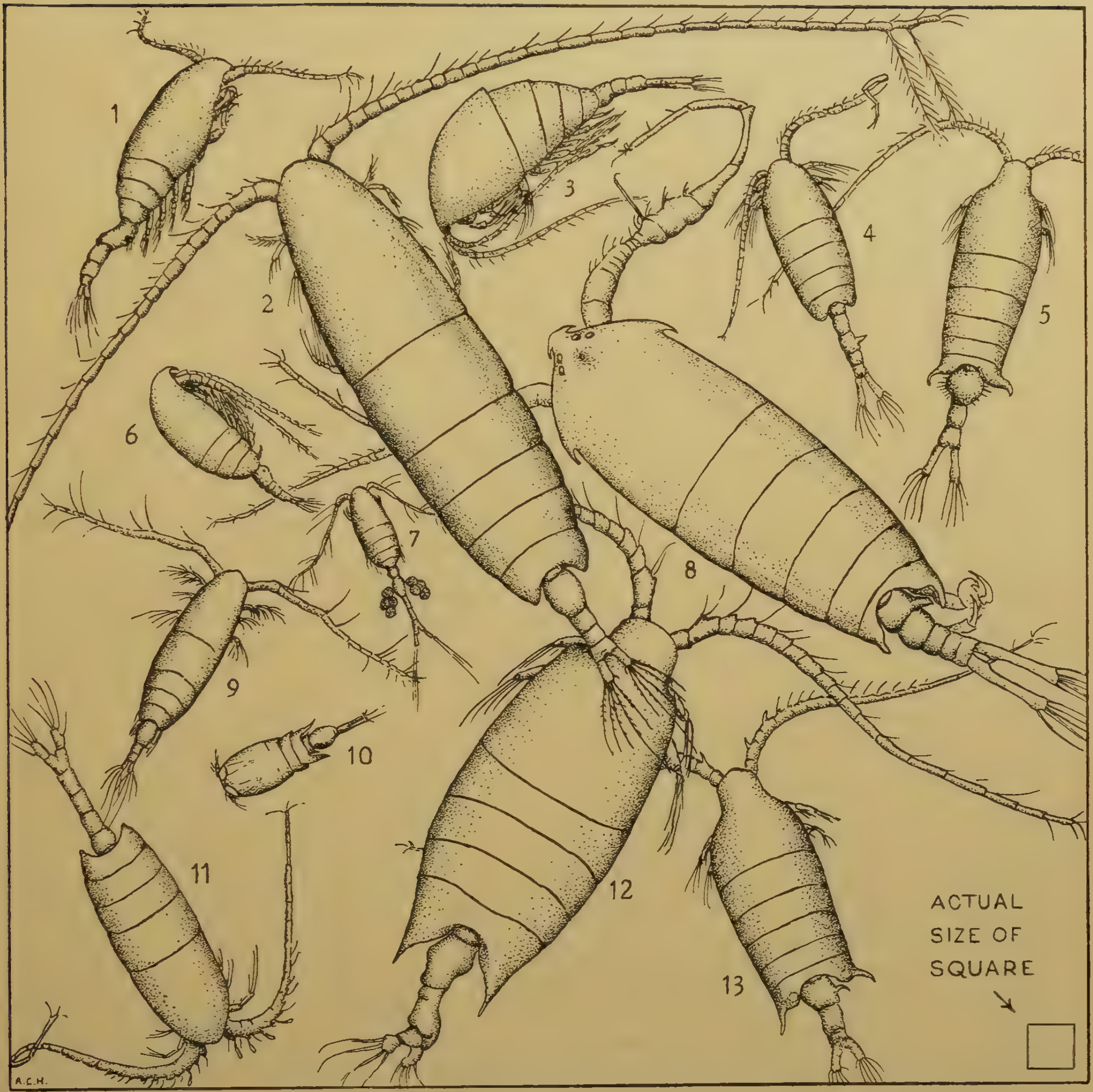

FIG. 13.—Sketches of the more important Copepoda (small shrimp-like animals) of the plankton dealt with in 'Bulletin' No. 4. All are magnified to the same extent and the actual size of the area shown is $\frac{1}{4}$ of an inch square. Examples 4, 8 and 11 are males, the remainder females.

1. *Pseudocalanus elongatus*
2. *Calanus finmarchicus.*
3. *Temora longicornis.*
4. *Isias clavipes.*
5. *Centropages hamatus.*
6. *Paracalanus parvus.*
7. *Oithona similis.*
8. *Anomalocera patersoni.*
9. *Acartia clausi.*
10. *Corycaeus anglicus.*
11. *Metridia lucens.*
12. *Candacia armata.*
13. *Centropages typicus.*

spread throughout the area than others? When we find a markedly uneven distribution in the area, does such a pattern of distribution tend to be repeated at the same season in subsequent years?"

Firstly they treat the varying production of all the Copepoda together. Look at the distribution and abundance in 1935 as shown in Plates C and CI, and compare it with the previous years shown in the preceding plates. On Plates LXVII and LXVIII we see the production on the Bremen line compared month by month in different years in the same way as already explained for Dr. Lucas's plant forms (the curves for 1936 and '37 are not so detailed as in former years because of an alteration in the scale of working). See how the production varies in different years; compare the poor year of 1933 with bumper crops of 1935; see the very good autumn production of 1932. Similar charts are shown for the Rotterdam and Copenhagen lines; on the former compare 1935 with 1936 (Plate LXVI).

Similar charts are prepared for the more important different kinds of Copepoda which commonly occur (they have no simple English names): *Pseudocalanus* and *Paracalanus*, *Temora longicornis*, *Acartia*, *Centropages hamatus* and *Centropages typicus*; the appearance of rarer forms in just certain seasons and years is also recorded. A study of the charts of the commoner forms, together with those for the total Copepoda, provide the answers to the questions raised in their introduction and quoted above. The information obtained about the time and place of the occurrence of the rarer forms at intervals through the survey is of great interest in relation to water movements, especially the occurrence of the more oceanic forms.

The young herring, when it hatches out from the egg and swims up into the plankton, begins to feed on a number of different small animals and plants. Earlier work has shown that then, for a very important part of its life-history, when it is growing from a length of half an inch to that of an inch and a quarter, it feeds on little else but the copepod *Pseudocalanus*. Mr. Rae and Dr. Fraser show how the numbers of this little animal vary enormously from year to year and from place to place along the recorder lines of observation. Here may well be one of the causes of the fluctuations seen in the stocks of older herring. Similarly in regard to trawl fish Miss Ogilvie, of the Scottish Fishery Department, has shown how up to 90 per cent. of the food of haddock fry consists of young copepods. The relative survival of different broods must in part depend upon the available food supply during this critical period of a fish's life. Step by step the framework of the natural economy of the sea is being filled in.

On p. 234 we see graphs of the monthly production of Copepoda through the year, January to December (J, F, M, . . . D), averaged for 1933–37, as continuous line curves for the Copenhagen route (above) and the Bremen route (below); then superimposed upon each of them is a similar curve in broken line to represent the corresponding production on the more southerly Rotterdam route. Whilst the region of the Copenhagen and Bremen lines have their peaks of production at similar periods, the more southerly region has its maximum peak very much later in the year. Many other interesting points are raised and discussed, but this "interpretation" cannot do more than indicate to the general reader the sort of picture that is emerging from the study of these changing planktonic populations.

'BULLETIN' No. 5.

This does not deal with the plankton recorder survey, but relates to the plankton collected by the small plankton indicator in the Shields herring fishery during the experiments already referred to on p. xviii. Mr. Savage, of the Ministry of Fisheries, was making a study of the food of the herring in the Shields area *at the same time*; his results were published in 1937. Mr. C. Cheng, a graduate of the National Tsing-Hua University, China, who came to this country to study fishery research methods, undertook a comparison of the plankton as collected by our indicators and that found by Mr. Savage in the stomachs of herring taken in the same fishery. Mr. Savage analysed his herring food material into 10-day periods throughout the summers of 1931, '32, and '33; Mr. Cheng separated all the available plankton indicator samples into the corresponding periods to match. Here we have a very interesting study of the plankton looked at from inside and outside the herring by two independent workers over the same period of time. It will help us to answer this question: Does the herring take its food by individual acts of capture, selecting this or that more attractive item from the "menu," or does it blindly swim through the water, sieving out just what comes in its way, as does our plankton recorder? Many naturalists have believed the latter view to be correct; Mr. Cheng's findings, however, support the former. This again is not just an amusing point of natural history; upon it hangs much of consequence to the fishery.

While the proportions of the Copepoda Calanus and Temora in the stomachs may sometimes correspond fairly closely with the those in the plankton, at other times they may be very much higher. Copepoda such as Acartia and Oithona, other little crustacea called Cladocera and the young of bivalve shellfish are always in much larger proportions in the plankton than they are in the stomachs of the fish. In July and August, 1931, Calanus was very scarce in both the plankton and the stomachs, and at that time we find a remarkably close correspondence between the quantities of two other animals in the herring stomachs and the same two animals in the plankton. These animals are the little planktonic snail Limacina and the "arrow worm" Sagitta (see Fig. 14). There is no such correspondence at all in 1932 and '33, *when Calanus is available for the herring in plenty.* This correspondence in the quantity of Limacina and Sagitta in the herring stomachs and plankton of 1931 is worth looking at; it is shown in the form of graphs on p. 252. The plankton curve is the continuous line and the herring stomach curve is the broken line. Is not the correspondence of the two curves for 1931 for both Limacina and Sagitta remarkable? Obtained by two independent workers by quite different methods it gives one confidence in the reality of ecological results. But what significance has all this for the industry? First it shows that the herring is not just blindly taking whatever food is there; it has preferences: it prefers Calanus if it can get it, hence the success of the commercial application of the plankton indicator already described. Let us now return to those commercial trials with the instrument when the Calanus-herring relationship was being tested. We saw on p. xxii that for the Shields area the plankton indicator during 1932 and '33, if properly used, would give an average increased catch of 21·2%, nearly as much as for the Scottish fisheries, but in July and August of 1931 at Shields it was a failure, reducing the average gain for the whole period of investigation to only 12·7% for the Shields area. We now see *why* it failed. The Calanus was so scarce during July and August, '31 (see Text-fig. on p. 250), that the fish were mainly going after Limacina and Sagitta rather than after the much scarcer Calanus. Little bits of the jig-saw puzzle fit together. The fishermen must not expect to get results with the plankton indicator if Calanus is scarce over the whole region. Our knowledge of the correct use of the plankton indicator is increasing. As the work goes on, as other little bits of the puzzle drop into place, its application and efficiency will no doubt be greatly improved.

'BULLETIN' NO. 6.

The last number of the volume concerns once more the main plankton survey, and deals with the distribution and abundance of the other members of the animal plankton apart from the Copepoda already dealt with in No. 4, and the young fish, which together with those for the 1938–39 survey will form the subject of a report in the next volume.

This paper has been much delayed and curtailed owing to the authors, Dr. Henderson and Mr. Marshall, both being on active service. It is more limited than the former reports for other reasons (see p. 256). It deals with the main general groups of different kinds of animals rather than with distinct species. However, in spite of its limitations this paper completes the picture of the changing plankton community in broad outline, and forms some basis for comparison for the more detailed future work.

Some of the more important members of these animal groups are shown in Fig. 14. Here we see the small planktonic snail Limacina, the arrow-worm Sagitta and the Cladocera all referred to in 'Bulletin' No. 5.

In the plates of this 'Bulletin' the varying quantities of plankton are shown, not as curves, but as numbers and symbols (for better comparison with the methods adopted in the later 'Bulletins'): the higher numbers are enclosed by circles which clearly show up the regions of greater abundance.

The outbursts of young forms (larvae) of bottom-living animals, such as Decapod larvae (the young of crab and lobster-like crustacea), Echinoderm larvae (the young of starfish and sea urchins) and the Lamellibranch larvae (the young

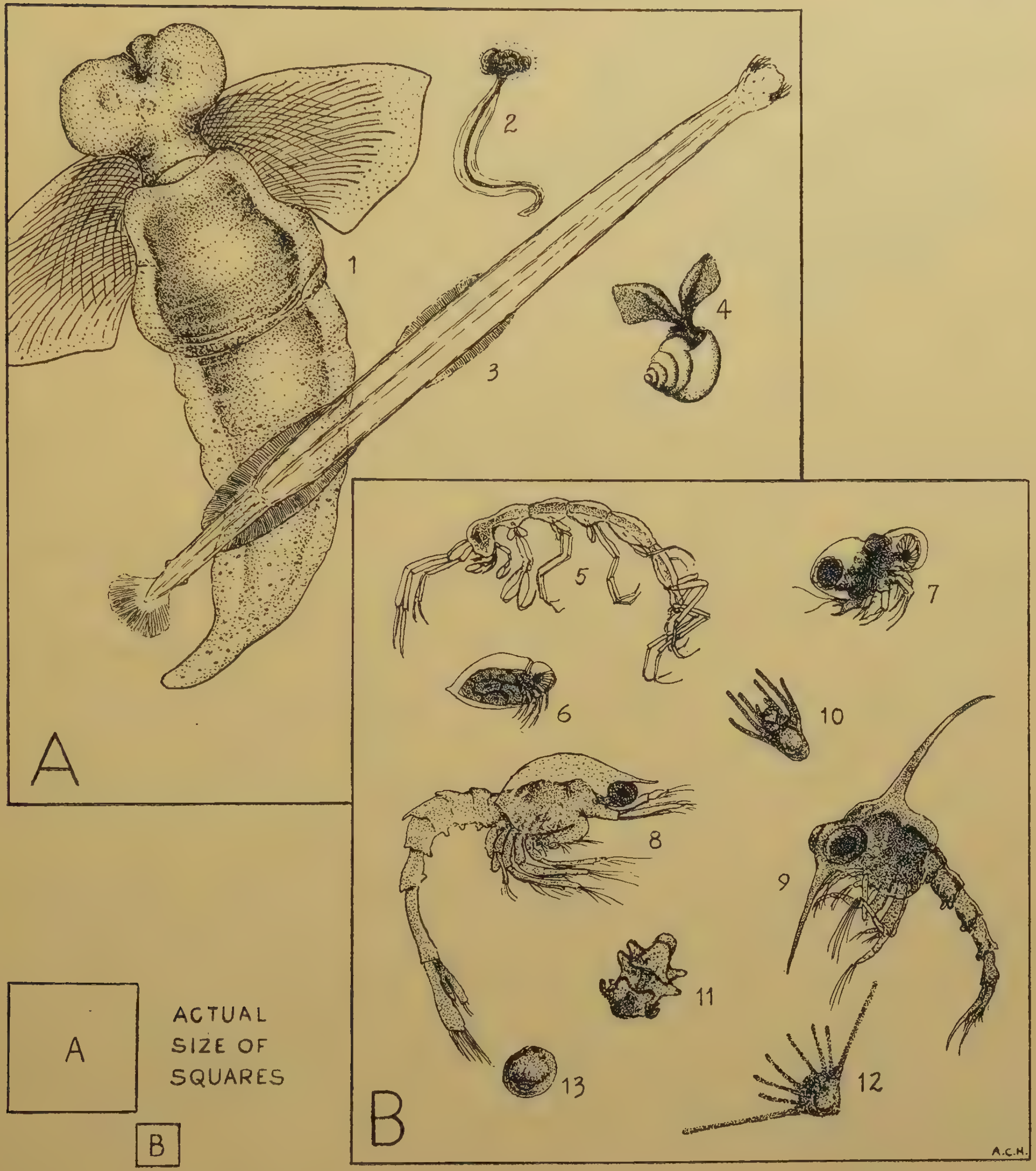

Fig. 14.—Sketches of the more important animals of the plankton (zooplankton) dealt with in 'Bulletin' No. 6. Those in square A are less highly magnified than those in square B, the actual sizes of A and B being $\frac{3}{4}$ and $\frac{1}{4}$ inch squares respectively.

1, *Clione limacina*; 2, *Oikopleura* sp.; 3, *Sagitta elegans*; 4, *Limacina retroversa*; 5, Caprellid Amphipod; 6 and 7, the Cladocera—Evadne and Podon; 8 and 9, Decapod larvae (young planktonic stages of shrimp and crab); 10, 11 and 12, Echinoderm larvae (young planktonic stages of sea urchin, starfish and brittle star); 13, Lamellibranch larva (young planktonic stage of bivalve mollusc).

of bivalve shellfish) are recorded. The bivalves are of great importance as the food of fish such as the plaice, and variations in their abundance over the Dogger Bank are particularly interesting in relation to the trawl fisheries (see pp. 264–266).

Diagrams on pp. 262–265 show in summary form the varying abundance of the more important animals month by month throughout the years for the three lines—Copenhagen, Bremen and Rotterdam. One is struck by the general poverty of the plankton in 1933—we saw that this applied also to the Copepoda discussed in ‘ Bulletin ’ No. 4.

The distributional characteristics of the different animals are compared: we see their tendencies to even or patchy production.

The papers of the present volume are just a beginning, a first attempt at showing how the *changing* plankton can be studied over wide areas, just as the changing weather conditions can be studied, with the passage of time. We are studying the plankton community in space and time. In the papers of the next volume, some of which are already published, we shall see similar pictures of changing abundance for the whole of the North Sea. As already indicated, further papers will attempt to relate these planktonic changes to those of the climatic and water conditions on the one hand, and to the fluctuations in the fisheries on the other. The war has interrupted this. Dr. Lucas was engaged on the former task, and had gone a long way towards its completion when he put it aside to take up special scientific work in relation to the war. All the members of the research staff are either serving in His Majesty's Forces or engaged on scientific war work.

I have acknowledged in ‘ Bulletin ’ No. 1 our debt of gratitude outside the College, to our financial supporters and many other helpers, and inside the College to our Council and Senate for all the encouragement and support we have received in the development of this work ; here I would like to end this general account of the first phase of our investigations with a simple word of thanks to all the members of my staff for their devotion to this work. The labour of all this analysis has been enormous ; the many difficulties of this pioneer period have not discouraged them ; their enthusiasm has overcome each obstacle. May it not be long before our team is drawn together again to pick up the fallen threads.

I have tried to show how one day, we believe, this work will develop to be of real service to the industry. It is a small beginning now, but were not the first series of weather maps poor things when compared with the forecasts of to-day which are of such service to marine and aerial navigation ?

[*Hull Bulletins of Marine Ecology, Vol. 1, No. 1, pp. 1–57, November, 1939.*]

ECOLOGICAL INVESTIGATIONS WITH THE CONTINUOUS PLANKTON RECORDER:

OBJECT, PLAN AND METHODS

BY

A. C. HARDY, M.A., D.Sc.

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INTRODUCTION.

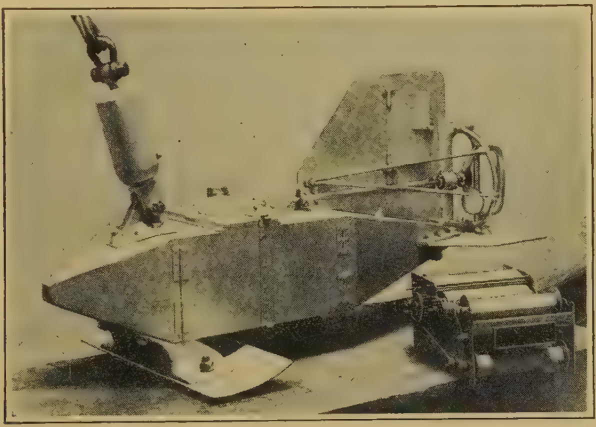
The idea underlying the initiation of this ecological survey was that of attempting to apply methods similar to those employed in meteorology to a study of the changing plankton distribution, its causes and effects.

For many classes of plankton investigation a special research ship is indispensable, but when one is concerned with the actual changes in distribution over a wide area, the use of a single research ship may prove inadequate. With the flow of ocean currents the distribution of the plankton may change rapidly. To make a reasonably detailed survey, using standard tow-net methods, a research ship must stop or slow down at frequent intervals to take her stations. If the area being examined is large and the ship begins its investigations, let us say, in the north, it is more than likely that the plankton of this part of the area will have undergone a change in distribution by the time the ship is finishing the survey in the south. One may not be able to get a picture of the plankton distribution as a whole at any one time. Again if it is the actual *changing* distribution and its causes that one is studying, it would be necessary to keep the research ship almost continually employed in making periodic surveys; the cost of such an investigation would usually be prohibitive.

During the *Discovery* Expedition to the Antarctic in 1925–27 the continuous plankton recorder was used for the first time (Hardy, 1926*b*). This instrument is fitted with planes, similar to those of the paravanes employed in the last war, so that when it is towed behind a ship it will dive below the surface and swim at a depth which may be determined by the amount of towing-rope veered out. As it is towed along it continually samples the plankton from the sea by means of a long gauze banding which is slowly wound across a water tunnel by the action of a propeller turned by the passing water. The gauze banding is graduated in numbered divisions. For every mile of sea through which the machine is towed a fresh section of the gauze strains off the plankton from the water and winds it on into a preservative chamber, where it is stored in formalin on a spool for future examination. The working of the instrument will be further described in a subsequent section (p. 10); a full account of the details of the mechanism, with scale drawings, has already been published (Hardy, 1936*a*).

When using the ordinary tow-net methods to cover an extensive area, the positions at which the samples are taken must, in the time available, be at considerable distances apart. Between two stations some important features of the plankton distribution, perhaps a concentration of copepods or diatoms, may be missed, or one station may happen to fall within a dense patch and give a false impression of abundance over a wider area. Numerous examples of such patchiness will be found in the reports on the survey which follow the present paper. A realization of the frequently patchy nature of the plankton led to the first experiments with the continuous recorder which, in addition to being used at full speed, gives a *continuous* line of ecological observation across the area being investigated (Hardy, 1936*b*).

The present survey was conceived as a means of studying the broad changes taking place in the plankton distribution of the North Sea and their relation to the changing hydrological and meteorological conditions on the one hand, and with the fluctuations in the fisheries on the other. A new pattern of continuous recorder was designed (Text-fig. 1); it was reduced considerably in size, for use by commercial ships, and improved mechanically to overcome many defects which were only too apparent in the first machine. By using several of these instruments, and by enlisting the co-operation of a number of shipping companies and their officers, it seemed possible to undertake a regular sequence of surveys of the North Sea, employing methods akin to those of meteorology. Just as a knowledge of the changing weather conditions has only been made possible by simultaneous observations being taken at a number of points over the area concerned, it seemed likely that such methods would succeed if applied to the changing conditions of the sea. A periodic survey was contemplated wherein several ships should use the continuous recorders at approximately the same time as they crossed the North Sea on different lines. Hull is an ideal centre for such a survey, for there are regular steamship routes radiating from the Humber in all directions across the North Sea.



Text-fig. 1.—The continuous plankton recorder as used in the North Sea survey; the internal mechanism has been taken out and placed alongside (*cf.* Text-fig. 4, on p. 11).

The scheme was first put forward in a public lecture on the relation of Science to the Fishing Industry, given at the University College of Hull on 16th October, 1929, and subsequently published (Hardy, 1930). With the aid of funds provided by the College, a substantial grant made from His Majesty's Treasury on the recommendation of the Development Commissioners, and grants from other bodies (see "Acknowledgments" on p. 53), the preparatory trials began in the autumn of 1931 and the survey proper in June of the following year. Dr. G. T. D. Henderson, B.Sc., Ph.D., and Mr. C. E. Lucas, B.Sc., were appointed research biologists in August, 1931, and a year later Mr. J. H. Fraser, M.Sc., was appointed as a Leverhulme Research Fellow, a post he held till 1935, when he was appointed to the staff of the Fishery Board for Scotland, and was succeeded by Mr. K. M. Rae, B.Sc., the present holder of the post. For the first five and a half years the survey was confined, as a trial, to the southern area before embarking on the contemplated study of the North Sea as a whole. A brief account of the methods used, illustrated by some examples of the results obtained in the first few years, was given at the 1935 meeting of the International Council for the Exploration of the Sea in Copenhagen, and published by the Council (Hardy, Henderson, Lucas and Fraser, 1935).

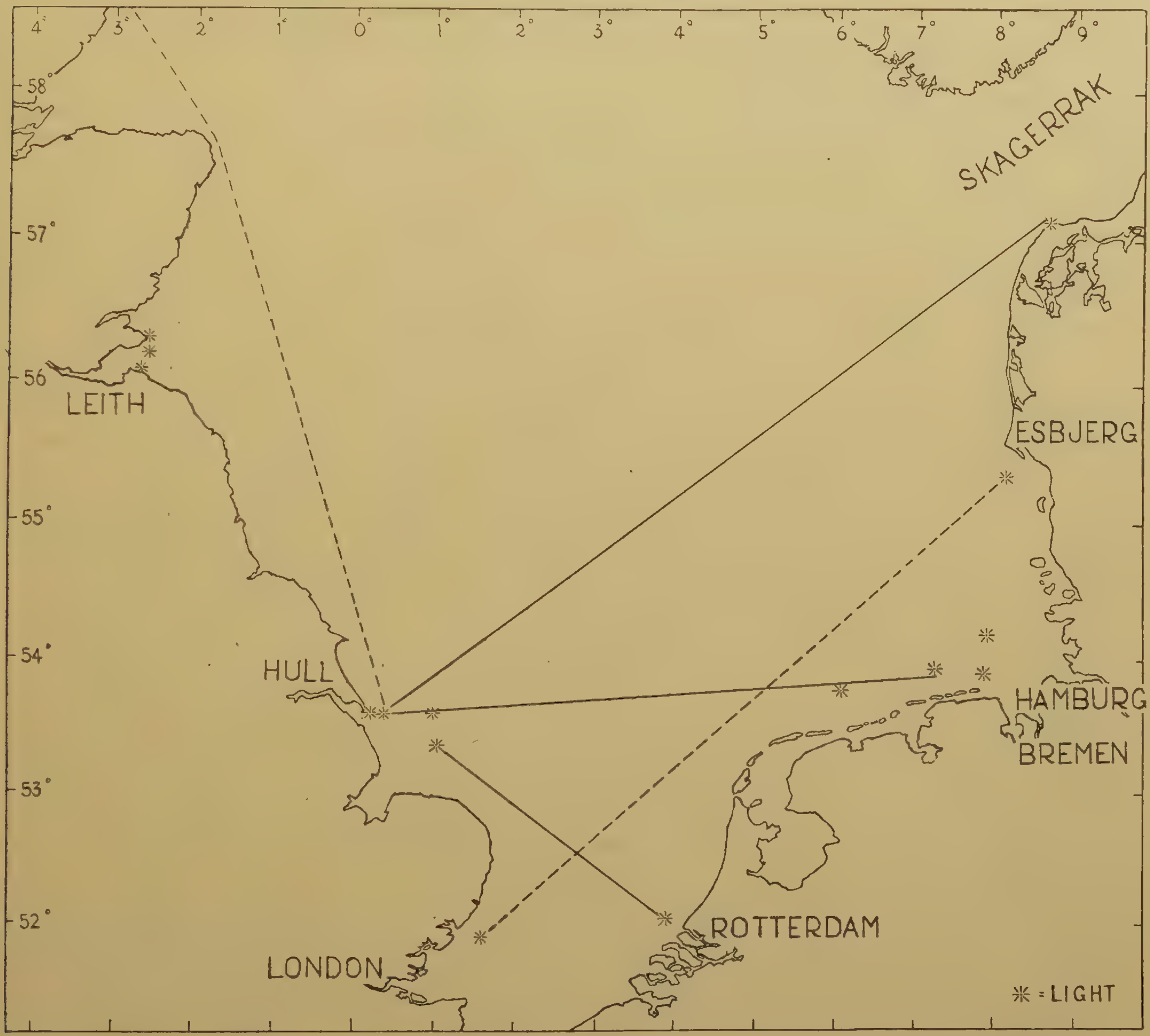
PLAN AND SCOPE OF THE SURVEY.

Text-fig. 2 shows a plan of the survey as operated from June, 1932, until the extension into more northern waters which began at the beginning of last year (1938). We started with three routes : Hull to Bremen (or Hamburg) on the line of the Argo Shipping Company, Hull to Rotterdam on the route of the Associated Humber Lines, and Hull to Copenhagen (for 250 miles towards the Skagerrak) on the Ellerman's Wilson Line. These were planned to be run every month and the three lines to be run close together in time. This was the ideal aimed at ; but it was not always achieved in practice, due to such accidents as mechanical breakdowns, stress of weather and alterations in ships' sailings. In 1933 an occasional line was started between Hull and the Pentland Firth on the route of the Icelandic Shipping Company to Reykjavik. With the limited number of machines at our disposal this was reluctantly discontinued at the end of 1935 in favour of a line on the London-Esbjerg route of the United Shipping Company. Whilst the line to the Pentland Firth was of great value (and we hope to reopen it again in the near future), it was thought advisable, to begin with, to concentrate as much as possible on a more complete survey of the southern area.

The recorders are run at a constant depth of 10 metres, chosen for the southern North Sea as the most suitable depth to give the most consistent results, having regard both for the phytoplankton and the vertically migrating zooplankton. Diagrammatic sections, showing the line of tow in relation to the sea-bed along the different routes, are given (Text-fig. 29) on p. 49, and the disadvantages of running at a single depth are fully discussed in a subsequent section on p. 48. Up to the present a gauze of a standard mesh, 60 to the inch, has been used. This was chosen as one which would effectively sample the metazoan plankton, and at the same time record the dense patches of the larger phytoplankton organisms in which we have a particular interest in relation to the fisheries. It is hoped in later models of recorders to combine with the present system a narrower banding of very much finer gauze for the smaller phytoplankton.

At the end of the first five-year period, the Development Commission, after an examination by their Advisory Committee on Fishery Research of the results so far obtained, recommended that the grant should be increased so as to add greatly to the scope and extent of the survey. The College also increased their contribution.

At a meeting in Edinburgh in September, 1936, to discuss the progress of the work with members of the staffs of the Ministry of Agriculture and Fisheries and the Fishery Board for Scotland, I invited members of the two departments to join in planning the future of the work so that it would best fit in with their programmes of research and those of the International Investigations generally.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TEXT-FIG. 2.—Chart of the southern North Sea plankton recorder survey of 1932–1937. The line from Hull to the Pentland Firth was an occasional line discontinued in 1935 and replaced by the London to Esbjerg line begun in 1936.

This invitation was accepted, and the extended survey which came into operation at the beginning of last year (1938) was planned by this Joint Advisory Board, on which I was joined by Dr. E. S. Russell, O.B.E., Director of Fishery Investigations, Ministry of Agriculture and Fisheries, and Dr. R. S. Clark, Scientific Superintendent to the Fishery Board for Scotland. A chart of this extended survey is shown in Text-fig. 3, and a brief account of this expansion will be given in a later section of this paper (p. 55).

The reports, which will be published immediately after this introductory paper, will deal with the results of the first five-and-a-half years, a period which must be regarded as definitely of a pioneering character, giving the basis of experience for the wider survey now in operation.

Before proceeding further to discuss the method of working, the interpretation of results, and the limitations to the method, it will be well to outline a little more fully the objects of the investigation. The similarity of the methods to those of meteorology has already been stressed : we are aiming at producing, month by month, charts of the broad changes in the distribution of the more important plankton forms.[1] It is then our aim to attempt to correlate these changes with the fluctuations in the fisheries, both the drift-net herring fisheries and the trawl fisheries, and also with hydrological and climatic changes. The correlation with the herring fisheries was one of the first economic results that was expected from such a survey. When the survey was first proposed there was evidence that dense concentrations of phytoplankton had an influence on the movements of the herring in that fewer herring appeared to be caught in areas where diatoms and the colonial flagellate *Phaeocystis* were taken in large quantities (Pearcey, 1885 ; Hardy, 1923, 1926*a* ; Savage, 1930). Since 1922 the Ministry of Fisheries have made surveys of the dense phytoplankton patches which appear in the southern North Sea at the times of the great autumn herring fishery ; a consideration of the distribution of these patches in relation to the fisheries from 1921 to 1932 led to the conclusion that such patches, both of diatoms and *Phaeocystis*, had the effect of acting as barriers to the migrating herring, and when they occurred near the usual fishing grounds had a deleterious influence on the fishery (Savage and Hardy, 1935 ; Savage and Wimpenny, 1936). As a preliminary to the present survey of the plankton in its relation to the herring fisheries, experiments were undertaken from this department with the plankton indicator, an instrument designed for use on fishing vessels, to obtain samples of the plankton at the places where the fish were caught. Between 1930 and 1934 we obtained over 1400 records of catches of herring with accompanying samples of plankton for correlation. These definitely showed (Hardy, Henderson, Lucas and Fraser, 1936) that on an average, during the spring and summer months when the herring were feeding, more herring were taken in water richer in their food *Calanus* than in water poorer in it, and that throughout the year the catches of herring tended to be low in water rich in phytoplankton. This preliminary ecological study developed into a more extensive piece of work than had been anticipated, and considerably delayed the working out and publication of the results of the first five years of the recorder survey[2] ; it also made it impossible to deal with the recorder rolls in the early years in

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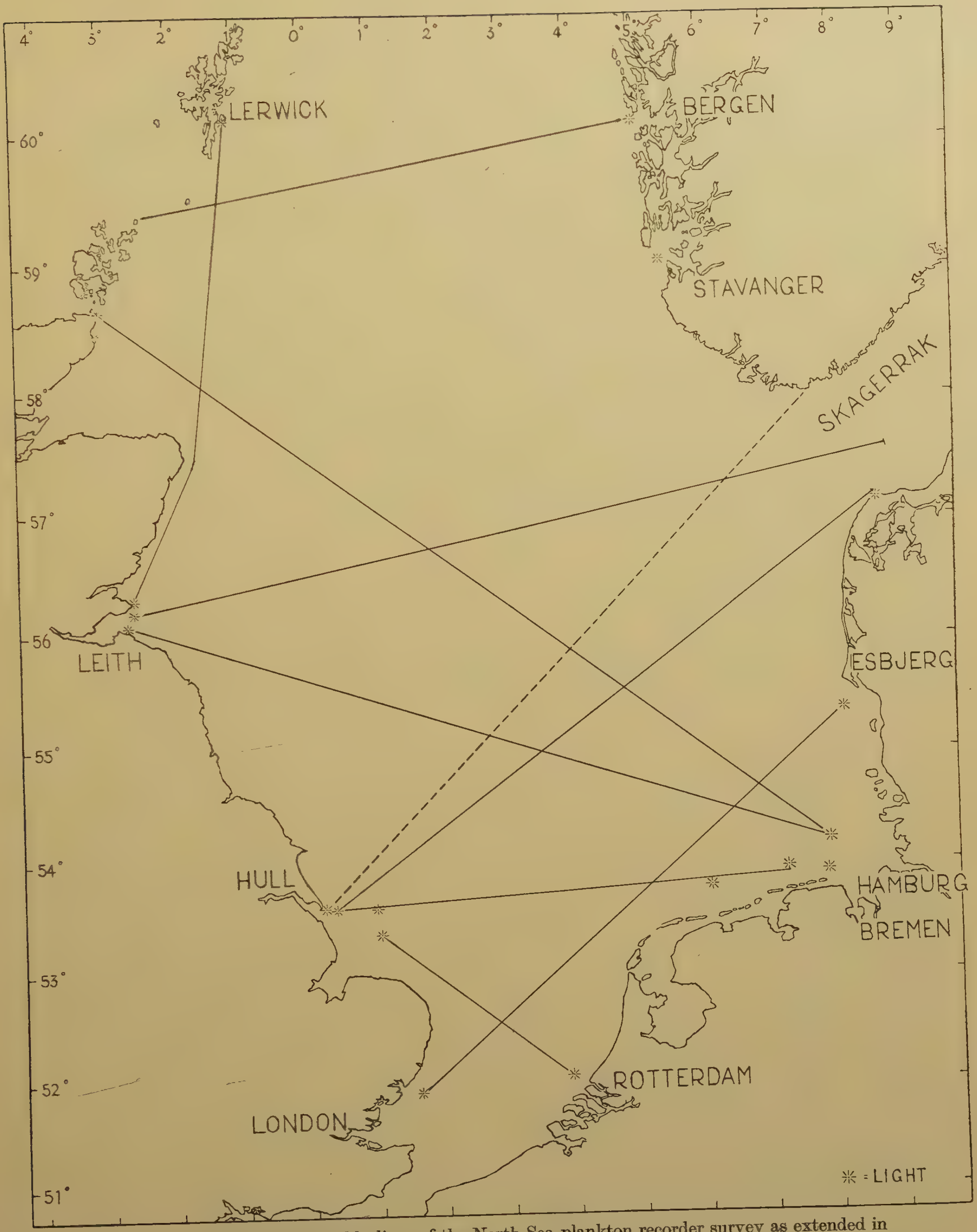
[1] Weekly traverses have been made on the Bremen line during the autumn since 1934, when charting phytoplankton in relation to the herring fisheries.

[2] Further delay was caused by the decision to issue our own series of publications.



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✳ = LIGHT

Text-fig. 3.—Chart of the monthly lines of the North Sea plankton recorder survey as extended in 1938. The line from Hull to Norway has been discontinued in 1939 and replaced by a new line across the Faroe-Shetland Channel.

anything like the detail we should wish and which we are now attempting. At first we had to confine the recorder work to yield information regarding only a few of the more important plankton species, and then to deal with such general groups as total Dinoflagellates and total Copepoda (except *Calanus finmarchicus* and later certain other species) or with genera such as *Sagitta*, *Limacina*, *Evadne*, *Podon*, etc. But we feel that this prolonged work with the plankton indicators has been well worth while, for it has established by the experimental method an ecological correlation between the distribution of the plankton and the shoaling of the herring. One of the main objects in concentrating our early survey in the southern area of the North Sea was an attempt to be of service to the herring fisheries by locating and reporting the position of any such dense patches of phytoplankton as might occur. This work is carried out in close co-operation with the Ministry of Agriculture and Fisheries. With the greater number of lines in the extended survey a better picture of the movements of these patches will be obtained, but already in the first five years the possible value of this work has been illustrated. The following is an extract from the Annual Report of the Development Commissioners for the year ending 31st March, 1937, p. 42 :

> " One result of direct economic application to English fisheries has already emerged from a limited use of the instrument. Early indications can be given of the existence and position of the vast floating " meadows " of tiny marine plants ; these masses of vegetation deflect and delay the migrating shoals of herrings on which depend the success of the East Anglian autumn fishery. The advance information thus gained assists the Ministry of Agriculture and Fisheries to map and to follow the movements of the patches of vegetation by means of the Department's research vessels."

The recording of these phytoplankton patches is dealt with in the report by Mr. C. E. Lucas following the present paper. It is hoped that when the extended survey has been in operation for a year or two we shall have the necessary experience to provide useful information to the herring industry regarding the areas where the herring food *Calanus* is most abundant, particularly in Scottish waters.

From month to month the distribution of the principal species of trawl fish varies considerably : the fish are more numerous now in this region and now in that. These distributions vary quite apart from the seasonal migrations to and from the spawning areas, and must be occasioned either by some very radical changes in the condition of the food on the sea-bed in different areas or by some hydrological changes in the North Sea. Whichever may turn out to be the over-riding factor, it seems not unlikely that a series of periodic charts of the plankton of the North Sea should in time enable a connection to be established between the distribution of the plankton and that of the trawl-caught fish. If the variations in the distribution of the fish are primarily correlated with changes in the benthic food supply, then it is likely that these in turn will be correlated with planktonic changes at some earlier date, for the benthic fauna is ultimately dependent upon the plankton for its food. If they are rather correlated with general hydrological changes, then the periodic charts of the plankton should yield valuable indications of these ; the results of the extended survey of last year show considerable promise in this direction.

If such correlations can be established between the plankton distribution and both the herring and trawling branches of the industry so that they serve as a guide to the more economic working of the fisheries, then one may expect sufficient support to be forthcoming to increase both the number of lines in the survey and the number of times they are run, so that charts and bulletins may be issued at short intervals.

This is one of the possible goals that is aimed at. The present investigation is in part to be regarded as a pioneer attempt towards a service of information to the industry which may be realized in the future—a service like that of weather forecasting. Direct economic results, however, beyond those already cited, must not be expected at once ; we are experimenting, building on experience often gained through failure and disappointment, and we must be cautious in our conclusions relating to the industry. The more immediate results will lie in the direction of affording a better understanding of the biology of the North Sea as a whole, which must indirectly and in time prove to be of economic advantage.

Particular attention will be given to the distribution of the pelagic eggs and young of trawl-caught fish as well as young herring so that comparative estimates of the new stocks of fish will be available. For this purpose, it is hoped, special traverses may be made, using a larger aperture to the recorder and a gauze of wider mesh so that greater quantities of water may be filtered and larger samples collected.

Attempts will be made to correlate the changing distribution of the plankton with the changing hydrological conditions of the North Sea as recorded by the various nations taking part in the investigations under the International Council for the Exploration of the Sea. Experiments are now being made with an instrument, built on the same lines as the plankton recorder, but designed to take water samples at intervals and provided with a continuously recording thermograph. If successful this will be run periodically on recorder lines, and so give records below the surface to supplement those at present taken at the surface by steamships co-operating in the International Investigations. Particular attention will be paid to the distribution of such plankton organisms as have been shown to be good indicators of different types of water, *e. g.* animals and plants which may indicate the strength and extent of the Atlantic inflow into the North Sea, and those which may be indicative of water of coastal origin. (See Russell, 1935.)

Another side of the correlation studies will attempt to link the distribution and varying production of plankton from season to season with meteorological conditions, *e. g.* the relation of the time and extent of the phytoplankton maxima to the varying sunlight of different years, the possible influence of heavy rainfall in this or that country upon the size of the area occupied by coastal waters as indicated by the distribution of neritic plankton. It is hoped that the survey may be the means of establishing a service of *marine phenology*, in that from year to year standard records will be available from different parts of the North Sea of the dates when this or that organism reaches a certain degree of density or when a decline sets in. Further, it is hoped that a survey which is yielding so many samples from different areas all taken in a uniform manner will provide valuable material for ecological studies of the plankton community, for example, positive and negative correlations between the distribution of different species, population problems, the nature and causes of patchiness, etc.

In addition to the general work of plankton analysis, each member of the staff[1] is undertaking one or other of these various branches as a special field of work. After the immediate issue of the reports covering the first period of five-and-a-half years, the papers to be published will be of two kinds. Some will be direct reports upon the results of the survey as such, and others will be studies relating the results to such wider problems as those just referred to. The latter will be published at intervals as stages in the investigations mature ; the former, if only in an abridged form dealing with a few of the more important organisms, will be published regularly soon after the end of each year so that they may become available as quickly as possible to other workers engaged on research in the North Sea.

The above outline of the aims of the survey represents the ideal towards which we are working ; it must be emphasized that the first years have been years of experiment and the efficiency of the system can still be much improved upon. For a number of reasons, such as shortage of machines, mechanical breakdowns, irregularity in ships' sailings, or stress of weather, it has not always been possible to run the different lines at approximately the same time, as desired, and at times records have been missed altogether. Again, it must not be pretended that the method is without its disadvantages ; its more important limitations will be dealt with in a subsequent section of this paper, and the more special limitations in relation to particular problems will be dealt with in the respective papers to follow. The method is not intended as a substitute for the older and well-tried methods of plankton research ; for many important classes of work it cannot take the place of the tow-net. It is intended rather as a complementary method of research designed to show in outline over a wide area the broad changes characteristic of the different seasons and different years.

Before proceeding further with a discussion of the methods of working and their validity it will be well to describe the instrument itself.

THE CONTINUOUS PLANKTON RECORDER.

A full description of the machine with scale drawings of all the parts and an account of its development from the first model have already been published in the '*Discovery* Reports', XI, pp. 459–488. It will, however, be convenient for reference to have a general account of it in the same volume as the reports on the results of its use in this survey. For all details of its structure and working the original account should be consulted, together with a reference to the recent improvements in design described on p. 24 of the present paper.

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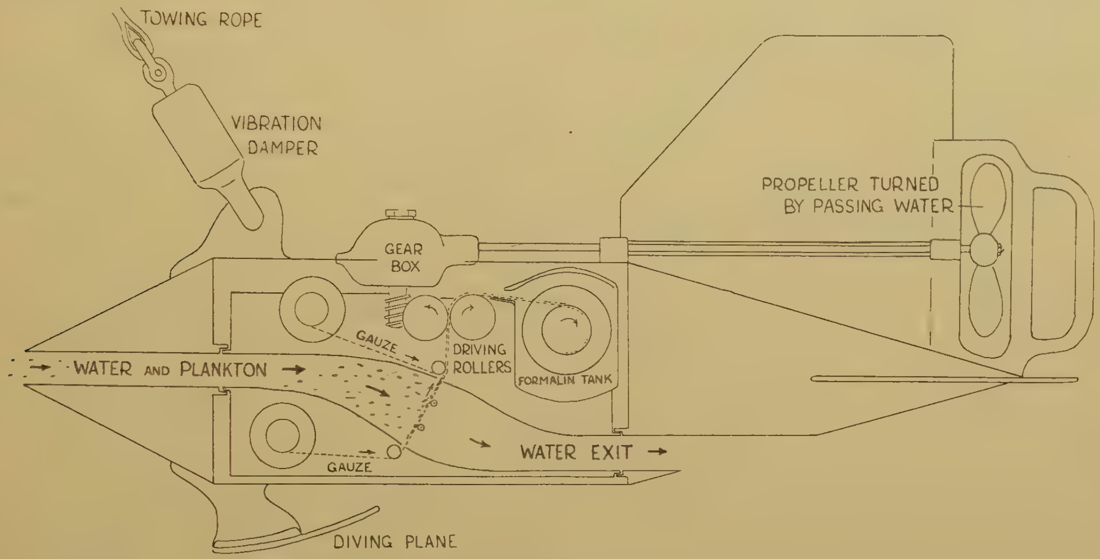
[1] Under the extension to the survey already referred to the staff has been increased by three additional appointments, see p. 55.

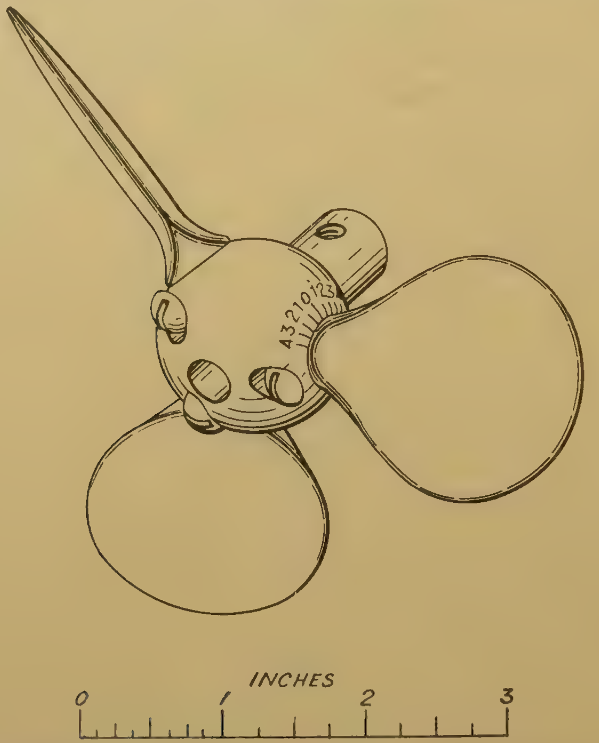
The general principles employed have been briefly indicated in the introduction and are illustrated in the diagram in Text-fig. 4. In the detailed figures which follow, the same series of reference letters will be used for the various parts. The machine consists of two main elements, the outer body and the removable internal mechanism; the reference letters allotted to the parts of the outer body will be shown as capitals, and those referring to parts of the internal mechanism as small letters.



Text-fig. 4.—Simplified diagrammatic longitudinal section through the continuous plankton recorder to show the general principles of its working.

The outer body is rectangular in cross-section, and consists of a main box-like central section which tapers to the opening of the water tunnel in front and to a point behind to give an approximation to a stream-line form. For use on commercial ships it was desirable to make the machines as small and compact as was compatible with stability in the water and efficiency in plankton sampling. The first machine to be made was cylindrical in cross-section and nearer to the perfect stream-line form, but since the cross-section of the internal mechanism has to be rectangular much space was wasted, and the size of the whole was unnecessarily large. The rectangular cross-section of the outer body in no way interferes with the stability of the machine; indeed, it is likely that its vertical sides help to prevent lateral movement as do the side panels of a box kite. Its total length is 3 ft. 4 in.; the dimensions of the various parts may be read off from the scale drawings in Text-figs. 6 to 9.

By stout brackets the diving plane is fixed below the body, so that the leading edge is directly below the front end of the box-section. Above is fixed a towing-eye to which is attached a shock-absorber designed to reduce the vibrational fatigue on the towing cable (see p. 30); it is in the form of a rubber compression block within a steel cylinder. The towing cable is shackled to an eye at the end of a rod which passes through the centre of the rubber block to the compression piston. To the tapering tail-section are fitted horizontal fins at the sides (continuous behind) and a large vertical fin above; in this vertical fin is inset a rudder, which may be set to counteract any tendency to go to starboard due to the rotation of the propeller.



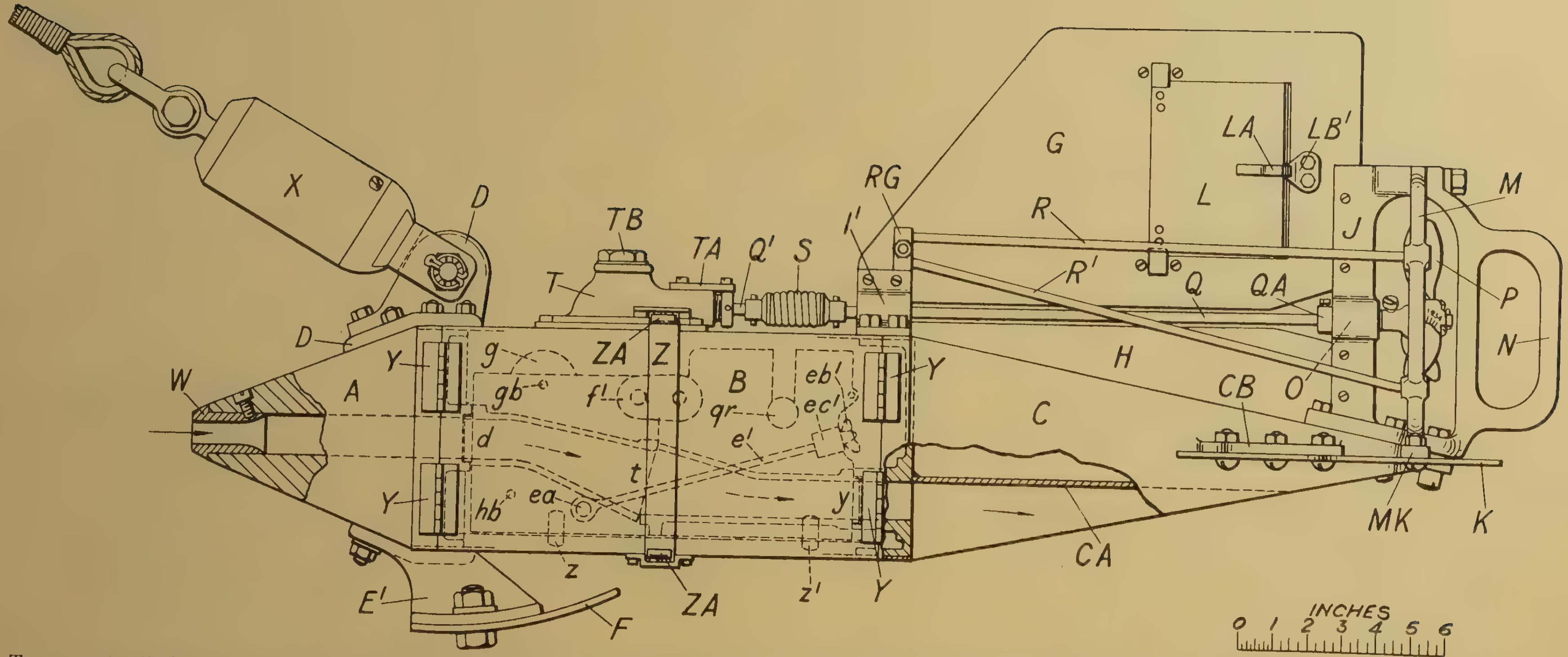
Text-fig. 5.—Propeller removed from shaft to show method of adjustment of blades.

The propeller, with adjustable blades, is situated aft and is protected by a ring outside, a bar behind combined with a lifting handle, and a pair of rods on each side connecting the ring to the front of the vertical fin. These guard rods were later additions found necessary to prevent fish, seaweed, etc., being caught in the propeller blades. On one occasion, before these were fitted, a dogfish was found decapitated and jammed in the propeller ring. The propeller (Text-fig. 5) consists of three blades each $2\frac{3}{8}$ in. long from boss to tip and $1\frac{3}{4}$ in. wide at its widest part. These are set in a cast central boss and each secured in position by a screw. By means of these screws they may be fixed at any desired angle, so that the pitch of the blades may be altered to give a choice of speeds of revolution in relation to the passing water, and thus a choice of speed for the winding on of the gauze bandings in the internal mechanism. Each section on the gauze may therefore be made to represent one or more miles of sea traversed as desired. A numbered scale is provided on the boss against each blade so that each may be correctly adjusted by bringing an engraved line on the blade opposite a particular point on the adjacent scale. The propeller shaft passes forward through a bearing, divides the vertical fin into two parts, and connects by a flexible joint with a drive shaft entering the gear-box. The gear-box, which is kept filled with oil, is situated in the top of the box body; in the illustrations its top will be seen projecting upwards as a dome furnished with a cap for replenishing the oil supply.

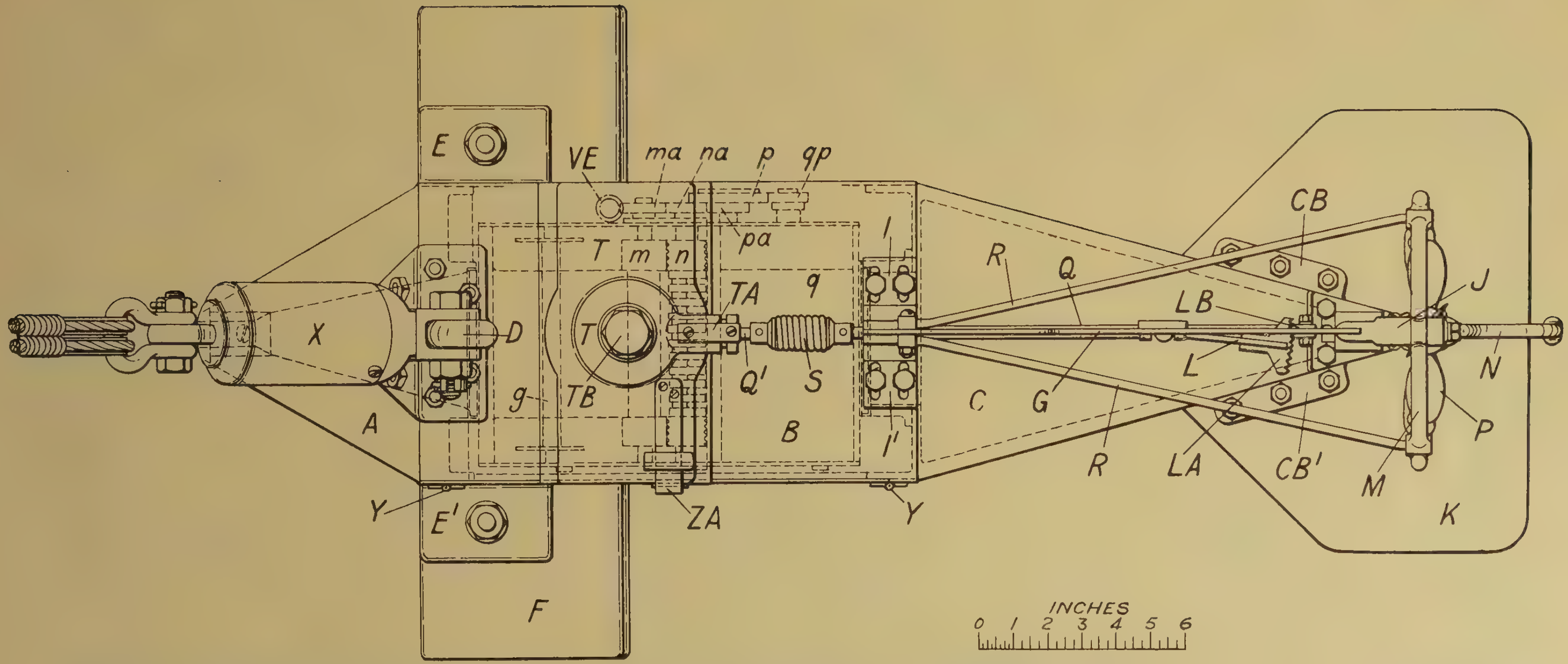
The opening to the water-tunnel in front is 1¼ in. square, but may be reduced to 1, ¾ or ½ in. square (or less) by fitting in small nose-pieces. From the beginning of the present survey to the middle of 1937 the opening was ¾ in. square; then it was reduced to ½ in. square as explained on p. 47. The tunnel widens out to a rectangular cross-section, 4 by 1¼ in., where it joins the tunnel passing into the internal mechanism frame, which can be slid out for loading. The movable section of the tunnel (*i. e.* in the mechanism frame) slides into grooves in the fixed part of the tunnel in front and behind, and when closed makes a tight joint. The tunnel continues behind the movable frame to open beneath the tail-section. All the space between the water-tunnel and the tapering body-wall of the front section is filled with lead to bring the centre of gravity of the machine as far forward as possible. The machine weighs 156 lb. (including the shock-absorber), and the centre of balance (with the shock-absorber removed) is 12½ in. behind the front of the machine (without nose-cap).

The towing cable, which makes an inverted catenary curve in the water, descends to the towing head at a steep angle (see Text-fig. 15). This being so there is no disturbance in the water in front of the opening to the water-tunnel, which is at the extreme front of the streamlined body of the machine; the entrance to the water-tunnel therefore cuts the virgin water cleanly, so that the organisms are swallowed in the stream of water without warning. In the ordinary tow-net, where the bridles and towing-rope precede the entrance, a number of the more agile animals may escape capture by darting aside at the approach of the ropes. This absence of obstruction is important with so small an opening.

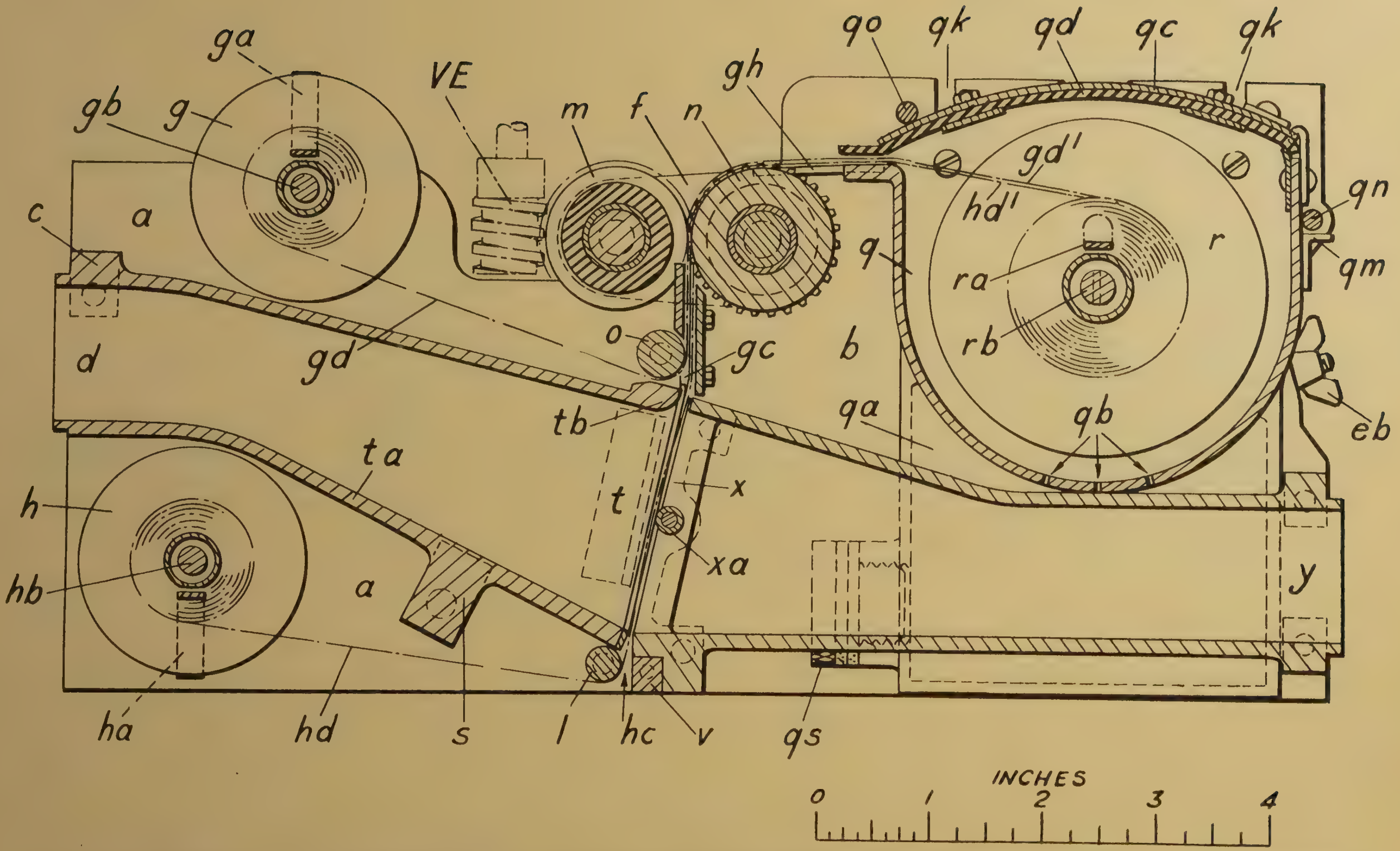
Through the internal mechanism frame the water-tunnel takes a slightly sigmoid path in the vertical plane in order that the minimum of space should be wasted in arranging the system of spools and storage tank. As it passes backwards the tunnel gradually widens to a cross-section 4 in. wide and 2 in. deep at the point where it is traversed by the gauze banding (see Text-figs. 6 and 8). In plan the tunnel is slightly asymmetrical on account of the mechanism frame having to be displaced to the left to allow space on the right for the worm-drive (*VE*) from the gear-box above (see Text-fig. 7) to the train of gear-wheels. To have placed it centrally would have meant an increase in the width of the machine and wasted


X
D
TB
TA
Q'
S
I'
RG
G
LA
LB'
M
R
L
J
R'
Q
QA
P
T
D
W
A
Y
g
gb
ZA
Z
f'
B
qr
eb'
ec'
e'
Y
H
CB
O
N
C
d
t
Y
hb
ea
y
MK
K
CA
z
E'
F
ZA
z'
Y
INCHES
0
1
2
3
4
5
6

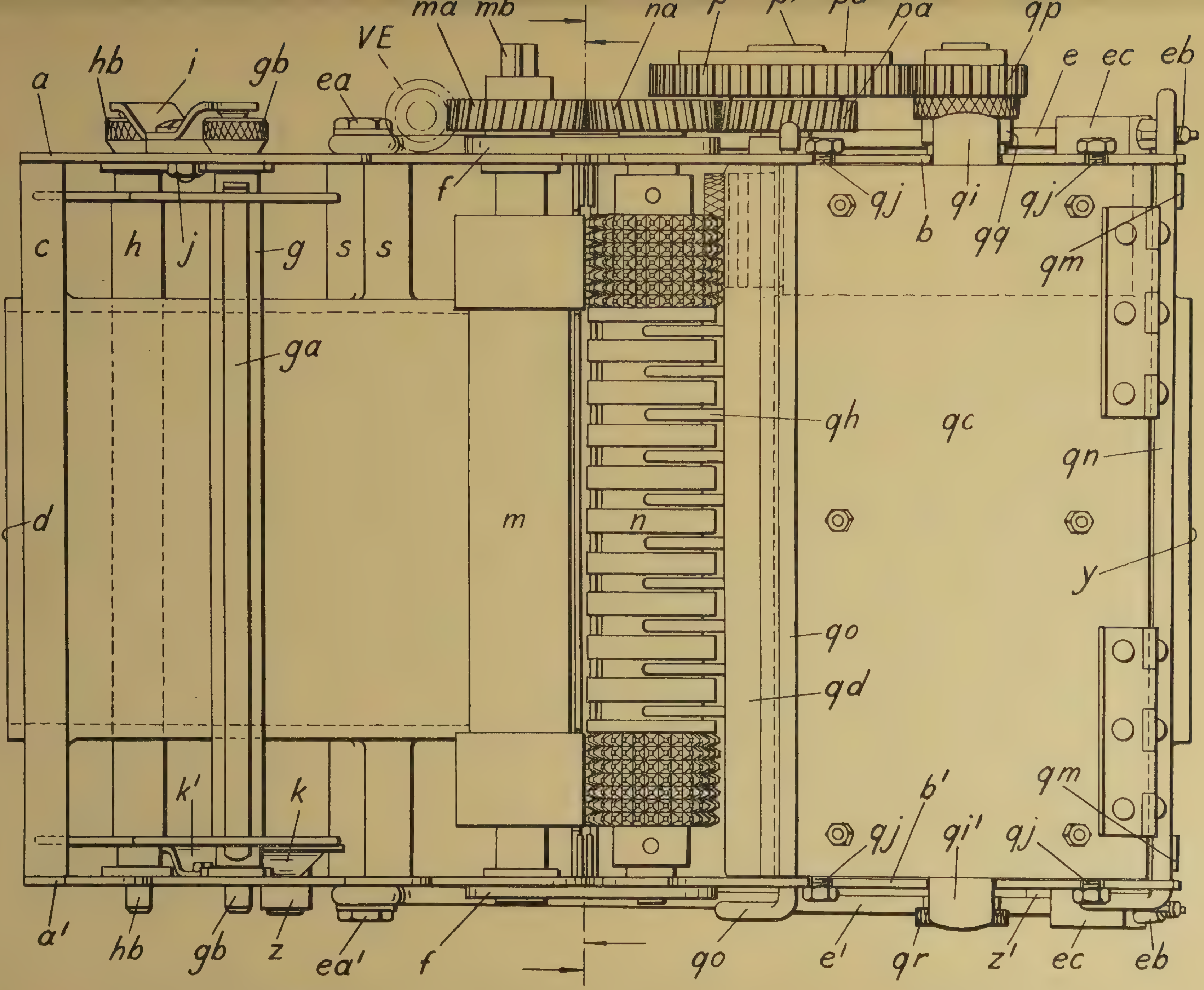
TEXT-FIG. 6.—Scale drawing of the continuous plankton recorder seen in elevation from the left-hand side. The entrance to the water-tunnel in front and its exit behind are shown in section. The internal mechanism frame and the path of the water-tunnel are shown in broken line; this outline should be compared with the enlarged sectional drawing in Text-fig. 8. In this and the following figures the capital letters refer to parts of the outer body and the small letters to parts of the internal mechanism; a list of the reference letters and their explanation will be found in the text, p. 22.


E
VE
ma
na
p
qp
pa
T
m
n
I
R
Q
CB
J
LB
TA
q
X
D
T
Q'
S
L
N
g
TB
C
G
A
B
I'
P
R
LA
CB'
M
Y
E'
ZA
Y
K
F
INCHES
0 1 2 3 4 5 6

TEXT-FIG. 7.—Scale drawing of the continuous plankton recorder seen in plan from above. The internal mechanism frame and the path of the water-tunnel are shown in broken line. The reference letters are explained in the text, p. 22.

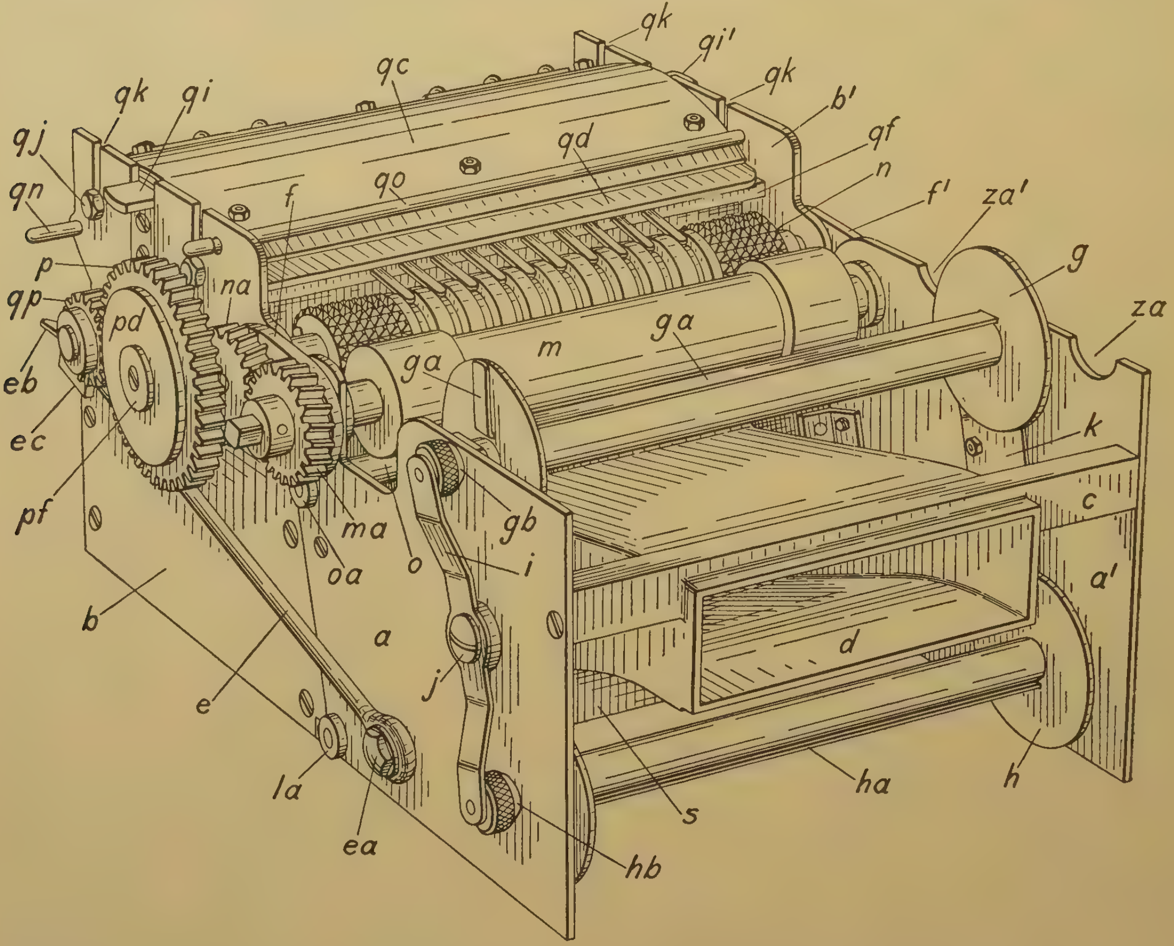

ga
gb
g
VE
m
f
n
gh
qo
qk
qd
qc
qk
c
a
gd'
hd'
qn
q
ra
r
qm
o
gc
b
rb
d
gd
tb
qa
qb
eb
ta
h
t
x
xa
y
hb
a
ha
hd
s
l
hc
v
qs
INCHES
0
1
2
3
4

TEXT-FIG. 8.—Optical section of the internal mechanism drawn looking *towards* the right-hand side, *d* and *y* being the entrance and exit of the water-tunnel respectively. The paths taken by the two gauze bandings are shown as *gd*, *gd'* and *hd*, *hd'*. For further letter references see text, p. 22.


a
hb
i
gb
ea
VE
ma
mb
na
p
p'
pa
qp
e
ec
eb
c
h
j
g
s
s
f
qj
b
qi
qq
qj
qm
ga
gh
qc
qn
d
m
n
y
qo
qd
k'
k
qm
b'
qj
qi'
qj
a'
hb
gb
z
ea'
f
qo
e'
qr
z'
ec
eb

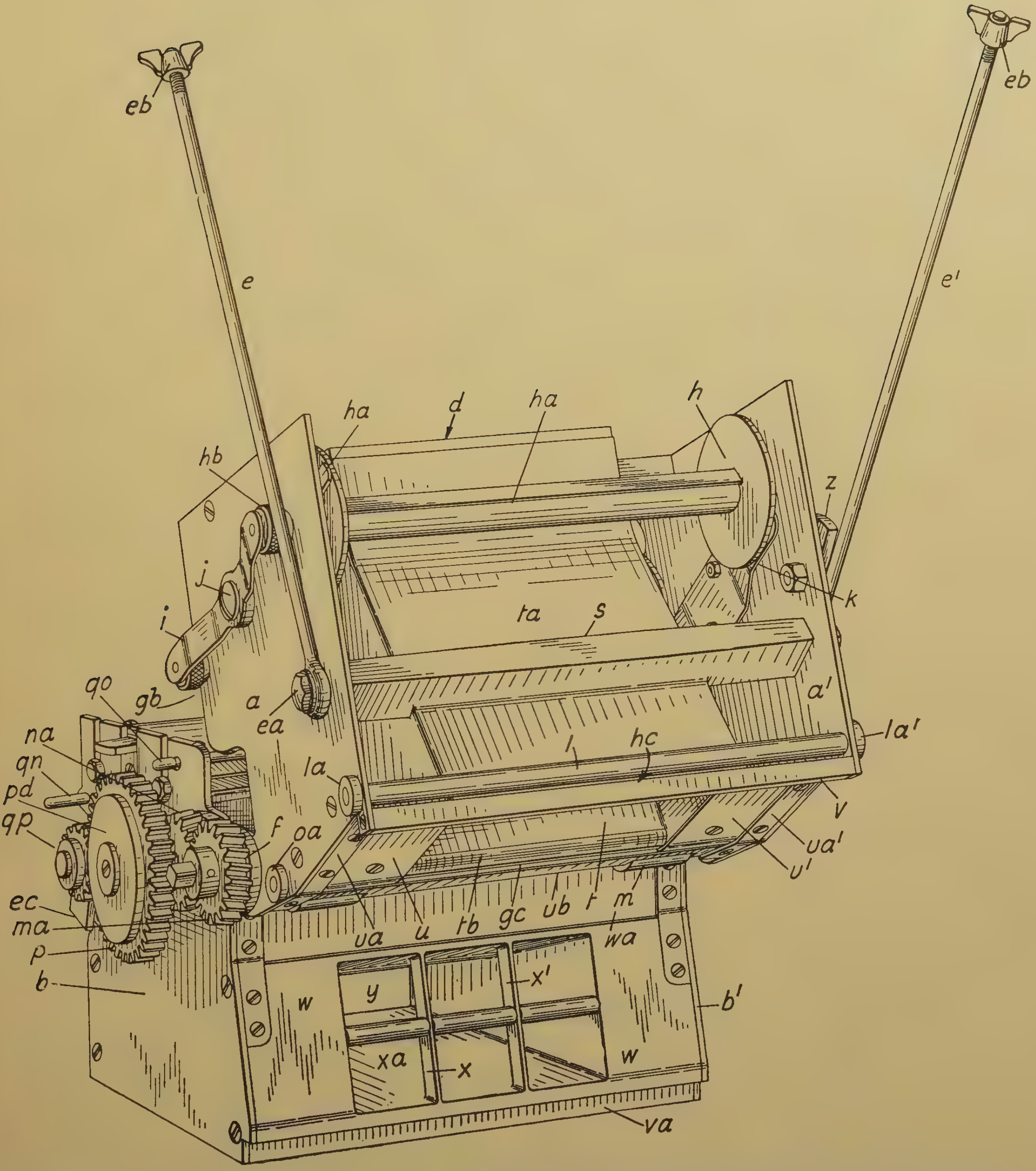
TEXT-FIG. 9.—The internal mechanism frame seen from above and drawn to the same scale as Text-fig. 8. For letter references see text, p. 22.

space on the left; the reduction in size, and so resistance to the water, is considered of great importance in a machine which may be used from commercial ships at speeds up to 15 knots. The movable frame holds all the mechanism except the gear-box, which is fitted in the roof of the box body. When the frame is slid into position the worm from the gear-box engages with cogs on a gear-wheel on the right-hand end of the forward driving roller *m*; this gear-wheel engages with another on the rear driving roller *n*, which in turn drives a series of gears incorporating a special friction drive rotating the storage spool *r* placed within a preservation (formalin) tank *q*.



Text-fig. 10.—Perspective drawing of the internal mechanism frame seen from the right front with the two parts locked together by the clamping rods *e* and *e'* (the latter out of sight). For further references see text, p. 22.

A graduated gauze banding winds off a spool *h* placed below the tunnel, passes back round a small roller *l* and up through a slit to traverse the water-tunnel. In crossing the tunnel it strains out the plankton, and is supported behind by


eb
eb
e
e′
ha
d
ha
h
hb
z
j
k
i
ta
s
qo
gb
a
a′
ea
na
qn
pd
qp
la
l
hc
la′
f
oa
v
ua′
u′
ec
ma
p
b
ua
u
tb
gc
ub
t
m
wa
w
y
x′
b′
xa
x
w
va

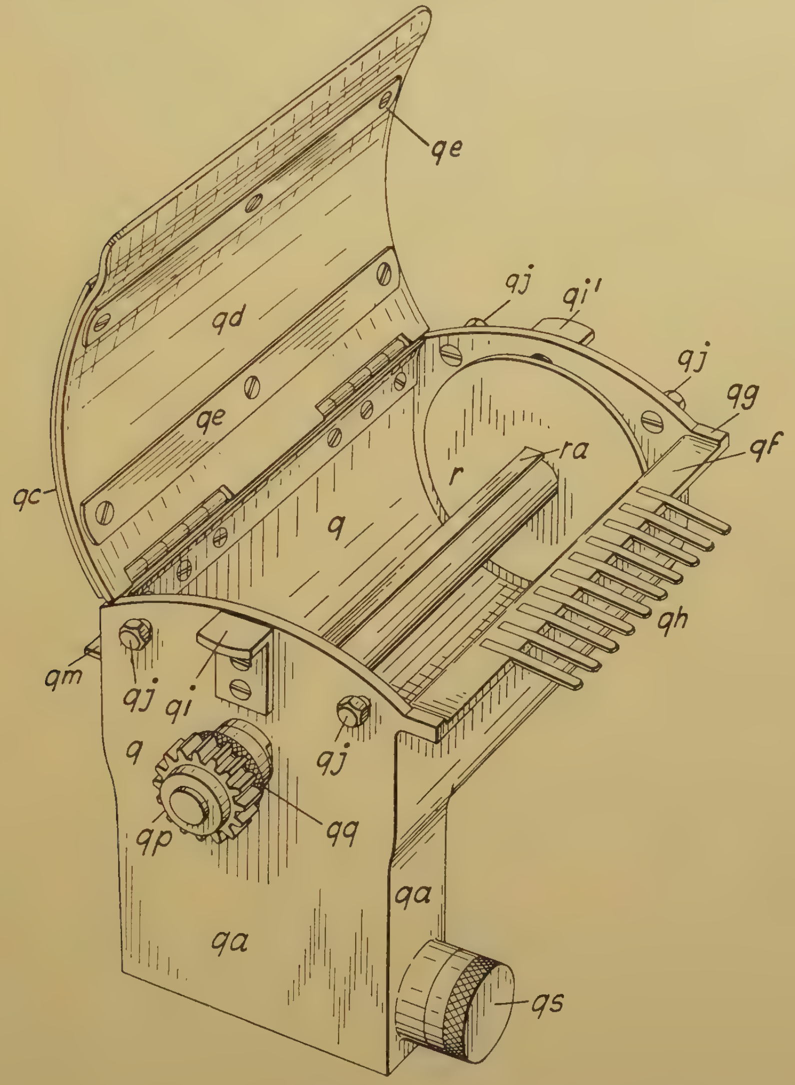
Text-fig. 11.—Perspective drawing of the internal mechanism frame seen from the right front with the clamping rods *e* and *e′* released and the two parts of the frame swung open about the hinge-plates *f* and *f′* ready for loading the gauze bandings. For further reference letters see text, p. 22.

vertical bars and small horizontal rollers. It leaves the tunnel by a slit and is immediately joined by the second gauze banding which has wound off a spool *g* placed above the water-tunnel. The two spools, from which the bandings wind, rotate on spindles which may be slid out from the right-hand side to allow of their removal; when loaded these spindles are held in place by a spring clip *i* on the right-hand side. The tension on the bandings may be adjusted by means of spring tongues *k* acting as brakes on the ends of the spools.

The two gauze bandings, having met, pass up together between the driving rollers *m* and *n*, which grip them tightly at their edges by means of the blunt teeth on roller *n* pressing into the rubber ends of the other roller. These rollers thus only meet at their ends, leaving a gap between for the rest of their length to allow the plankton imprisoned between the gauze bandings to pass through without being unduly crushed. The bandings pass on together on to the storage spool *r* which is placed inside the tank *q*, which is filled with a 20% formalin solution. This spool may be removed by sliding out a spindle on the left-hand side after the removal of a cap which holds it in position. The storage spool until recently was driven by the slipping friction-drive, contained in the large gear-wheel *p*, so that it just took up the slack on the gauze bandings as they issued from the driving rollers; without such a device the gauze bandings would be wound on at a faster and faster rate as the diameter of the roll increased with the fresh layers of gauze wound upon it. Experiments have now been made with a direct drive incorporating a conical fusee similar to that employed by clockmakers; it has proved very successful, and is described in detail in a special section on p. 24.

The silk bandings are lifted off the rear driving roller by a series of comb-like teeth, which project from the lip of the entrance to the formalin tank and fit into grooves in the roller (see Text-figs. 9, 10 and 12). The lid of the formalin tank is lined with rubber which, when closed by the rod *qo*, makes a watertight joint at the sides and back; there is a narrow gap in front between the lid and the lip for the entry of the gauze bandings. The escape of the formalin through this entry is largely prevented by the soft rubber lining to the lid extending out beyond the lid to press lightly on the incoming bandings. Nevertheless, some loss of formalin takes place when the machine is immersed in water; but this loss is made good by the slow diffusion of formalin through small perforations in the bottom of the tank from an auxiliary tank filled with cotton-wool and neat formalin (40% formaldehyde solution) placed below it on the right-hand side (Text-fig. 12, *qa*). The strength of formalin in the main tank will thus be maintained throughout a run across the North Sea.

The internal mechanism frame is in two parts, which may be partially separated from one another for the loading of the gauze bandings. It is divided along the line where the gauze crosses the water-tunnel, and the two parts pivot one on the other about the driving rollers, but may be drawn a little way apart to allow the gauze bandings to be passed between the rollers (see Text-fig. 11). On each side of the forward part are hinged two long rods furnished at their extremities with wing nuts, which by engaging against slotted lugs on the rear part draw the two parts tightly together. When so drawn together the driving rollers tightly grip the gauze bandings, as explained above, and a system of plates prevents the escape of water from the bottom and sides of the water-tunnel.



Text-fig. 12.—The formalin tank removed from the mechanism frame and drawn with the lid open to show the storage spool in position. Note the flask of neat formalin *qa* from which, by diffusion through perforations, the strength of the formalin in the tank is maintained. For further reference letters see text, p. 22.

The graduated gauze banding which strains out the plankton is ruled with transverse lines 2 inches apart. Each section thus exposes an area 2 in. by 4 in. to the water stream and, the gauze banding being 6 in. wide, there is a 1 in. margin on each side of the water-tunnel passing up in a shallow recess in the plates just mentioned. The force of the water through the tunnel keeps the plankton pressed against the gauze till it passes up through the exit slit, to be joined by the second banding. The driving rollers are so placed as to press the banding against the back of the slit so that the plankton is not scraped off by its forward edge. The large exit behind ensures that the water passes through the gauze (the opening to the tunnel in front, if $\frac{3}{4}$ in. square, is only one-thirteenth[1] of the cross-section of the tunnel at the gauze), and water cannot escape at the sides ; a little water will pass through the narrow slits through which the gauze banding enters and leaves the tunnel, but this escape is negligible since the slits communicate with a closed space within the box body.

The following is a list of the letter-references found in Text-figs. 6 to 12 with their explanations :

Capital letters referring to parts of the outside body :

A. Front section of outer body tapering to opening of water-tunnel.
B. Box-like central section of outer body.
C. Tail section of outer body tapering to a point.
D. Towing eye.
E. Brackets securing diving plane to body.
F. Diving plane.
G, H. Two sections of vertical fin separated by propeller shaft.
I, J. Castings securing fin-plates **G** and **H**.
K. Horizontal tail fin.
L. Biasing rudder set in vertical fin.
M. Guard ring round propeller.
N. Rear propeller guard and lifting handle.
O. Propeller shaft bearing.
P. Propeller.
Q. Propeller shaft.
R. Rods to serve as guards for propeller.
S. Universal joint of coiled spring type.
T. Top half of gear-box.
U. Bottom half of gear box.
V. Reduction gearing (**VE** : worm which drives gear train in the internal mechanism).
W. Nose-piece castings, fitted into water-tunnel to reduce opening.
X. Shock absorber to take up vibrations in towing cable.
Y. Hinges of the two doors of the box section.
Z. Metal strip on forward door overlapping rear door and engaging with spring clips **ZA** to keep them closed.

Small letters, referring to parts of the internal mechanism :

a, a′. Right- and left-hand side walls of the front section of mechanism frame.
b, b′. Right- and left-hand side walls of rear section of mechanism frame.

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[1] See p. 41.

c. Cross-bar holding **a** and **a′** together.

d. Forward entrance to water-tunnel through internal mechanism.

e, e′. Clamping rods one on each side, serving, when tightened up, to hold the two sections of the frame together.

f, f′. Plates which act as a hinge about which the two parts of the frame may be swung open.

g. Spool from which plain gauze banding winds.

ga. Metal strip securing end of gauze banding to spool **g.**

gb. Spindle on which spool **g** rotates.

gc. Slit through which plain gauze passes to join graduated gauze above water-tunnel.

gd, gd′. Path of plain gauze.

h. Spool from which graduated gauze banding winds.

ha, hb. Similar to **ga** and **gb,** but referring to spool **h.**

hc. Slit through which the graduated gauze passes to cross water-tunnel.

hd, hd′. Path of graduated gauze.

i. Spring clip which holds spindles **gb** and **hb** in position.

j. Pin about which **i** rotates.

k, k′. Spring tongues acting as brakes on spools **g** and **h.**

l. Metal roller round which graduated gauze passes up to cross water-tunnel.

m. Forward driving roller of rubber.

ma. Gear-wheel, rotating freely on the spindle of roller **m**, and transmitting drive from worm **VE** to gear-wheel **na** secured to spindle of gear driving-roller **n.**

mb. Square end of spindle of roller **m** for attachment of winding handle to rotate rollers in loading and adjusting gauze bandings.

n. Rear driving-roller, recessed to accommodate comb teeth **gh** and with toothed end sections.

mn. Gear-wheel (see under **ma**).

o. Metal roller round which plain gauze banding turns.

p. Large gear-wheel containing friction-drive system.

q. Formalin tank.

qa. Reserve tank for formaldehyde.

qb. Position of perforations connecting **qa** with **q.**

qc. Curved lid of **q.**

qd. Rubber lining to **qc**, fixed by brass strips **qe**.

qf. Lip to entrance of formalin tank.

qh. Comb teeth, projections of **qf**, which fit into grooves in the rear driving-roller **n** and lift the gauze bandings from it.

qi, qi′. Lugs for lifting formalin tank out of mechanism frame.

qj, qk. Pins and slots for locating **q** in the mechanism frame.

qm, qn. Brackets and rod holding **q** in position in frame.

qo. Rod pressing on lid of formalin tank and keeping it closed.

qp. Straight-toothed gear-wheel engaging with friction-drive **p** and so rotating spool within tank.

qq. Packed bearing carrying storage-spool spindle.

qr. Screw cap securing the spindle **rt** for the spool **r** in the tank.

qs. Screw cap for filling reserve tank with formaldehyde.

r. Storage spool.

ra. Strip of metal securing the end of the gauze bandings to spool **r**.

rt. Spindle for storage roll **r**.

s. Cross-bar holding **a** and **a′** together.

t. Cross-section of water-tunnel covered by filtering surface of graduated gauze banding.

ta. Floor of water-tunnel casting.

tb. Curved edge of water-tunnel opening. This ends $\frac{1}{32}$ in. below the surface of the plates **u**, and so leaves a gap up which the plankton passes on the gauze.

u, u′. Plates against which the edges of the graduated gauze pass up ; they are $\frac{1}{32}$ in. below the plates **ua**, **ua′**, which, when the frame is closed, press tightly against the face **w** of the hind section of the frame. This arrangement allows a narrow recess to take the thickness of the gauze banding.

ub. Plate above the slit **gc**.

v. Cross-bar making close joint with the recess **va** at the base of the face of the hind section.

va. Recess into which fits the bar **v**.

w. Face cast in one with hind section of water-tunnel.

wa. Plate continuous with face **w**.

x, x′. Vertical bars crossing section of water-tunnel and holding **xa**.

xa. Horizontal rollers on fine spindles between bars **x**. These bars and rollers give support from behind to the gauze banding passing up across the tunnel.

y. Exit from water-tunnel.

z, z′. Pivoted locking tongues which secure the mechanism frame in position within the box section of the outer body.

za, za′. Cutaways in the left-hand side of frame to form finger-grips for withdrawing the mechanism.

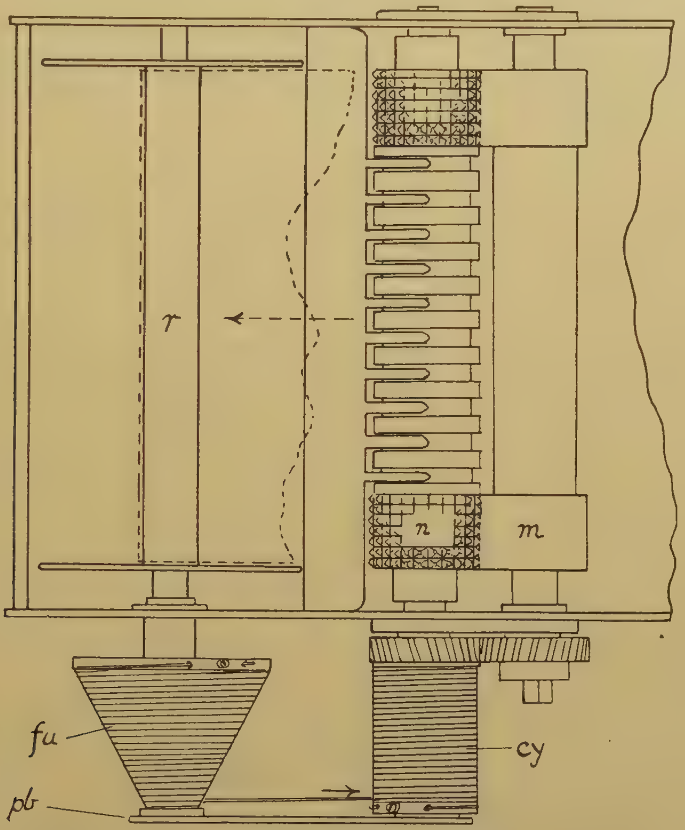
Recent Improvements in Recorder Design.

The plankton recorder described above, and in full detail in the '*Discovery* Reports', is the machine as used in the greater part of the 1932–37 survey. During 1937 an experiment was made with an alteration which has been so successful that it has now been incorporated as part of the standard design, and has been used for the greater part of the 1938 programme.

The part of the machine which had given the most trouble mechanically was the friction-drive system, which turned the storage roller in the formalin tank by being incorporated in a train of gears from the driving rollers (see p. 20). This was necessary so that the storage roller should just take up the silk as it came from the driving rollers ; had it rotated at a constant rate, the speed of winding would have increased as the diameter of the spool increased with the additions of more silk. There were two objections to this principle. Firstly, the friction-drive required very careful adjustment ; if it was either too tight or too slack a failure in the mechanism might occur, and this proved to be one of the chief sources of failure in the past. Secondly, the friction-drive kept the silk under tension, so that there was always some pressure tending to injure the specimens as they were wound up.

Several years ago my colleague, Mr. P. G. 'Espinasse, made the valuable suggestion that a fusee, that device used by the old clockmakers to compensate for the weakening of the spring, might be employed to give a direct drive to the storage spool, yet one which would retard its speed of winding in direct relation to its increasing circumference. At that time when we were using a ratio of 1·5 to 2 miles per section, the rolls were so long that such a device would have been too bulky to incorporate in the present size of recorder. When we made the change to a ratio of approximately 5 miles per section it became possible to use it, although even with this increased ratio it has meant building out a slight excrescence on the side of the recorder to accommodate the mechanism.

The device is shown in plan in Text-fig. 13. It consists essentially of the following parts: *cy* is a metal cylinder having a diameter equal to that of the driving roller *n*, on the extended spindle of which it is mounted so that it turns with it. The fusee *fu* is a metal truncated cone, the diameter of which at the base equals that of the storage spool *r* when fully wound and at its truncated apex that of the spool when empty. The fusee is mounted on an extension of the spindle holding the storage spool, so that a rotation of the fusee will turn the spool with it. Round both the fusee and the cylinder are cut spiral grooves to take a narrow steel wire of 0·015 in. diameter. The number of turns in this spiral on the fusee exactly equals the number of turns of silk gauze to be accommodated on the spool.



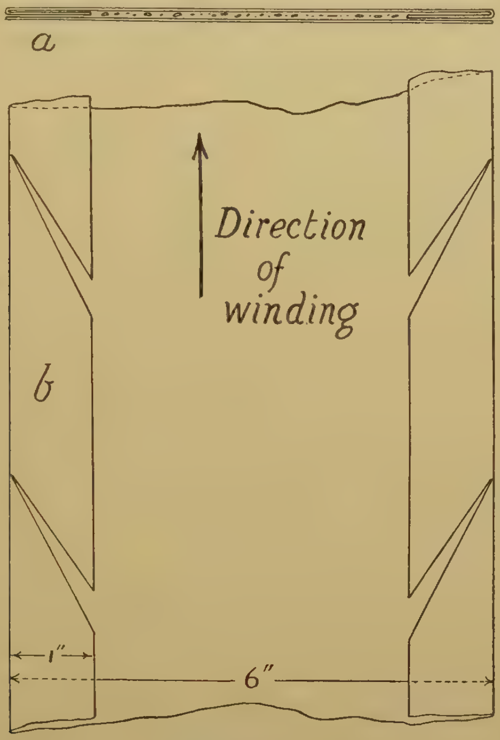
Text-fig. 13.—Diagrammatic plan of the new fusee mechanism; for explanation see text.

At the start of a record a length of the steel wire is attached by one end to the fusee by a small grub-screw at its base, wound tightly round the spiral of the fusee and its other end brought across to be attached by another small grub-screw to the outer end of the cylinder *cy*. As the rollers *m* and *n*, which drive forward the silk, are turned by the action of the propeller, the cylinder turns and winds up the wire off the fusee, which is thus rotated. The storage roller is turned by the fusee. Let us assume for simplicity that the recorder is being towed at a constant speed so that the driving rollers *m* and *n* are turning at a constant rate. The cylinder will also rotate at a constant rate, but the fusee will rotate more and more slowly as the wire is pulled from its wider and wider circumference. Since the cylinder *cy* has the same diameter as the driving rollers, the wire will be wound on to it at exactly the same rate as the silk passes up between the driving rollers. Since the number of turns of wire round the fusee equals the number of turns of silk that can be accommodated on the spool, the spool will be turned with a retardation which exactly compensates for the increased diameter of the silk which is wound upon it. We have a direct but compensating drive.

The tension on the wire is considerable, and failures were experienced at first through the cylinder and fusee being pulled towards each other so that the latter failed to turn and the wire broke. This was overcome by the introduction of the positioning bar *pb* which keeps them the correct distance apart. Many different wires were used before one was found fine enough, strong enough, and capable of withstanding the corrosive action of sea-water. The wire at present in use is that made by Messrs. Bruntons of Musselborough, and is their 0·015 in. diameter stainless steel wire.

Another improvement has been made without actually altering the construction of the machine. In the '*Discovery* Reports' already referred to, a section dealing with possible future developments in machine design contained a suggestion for reducing the pressure on the plankton when wound on the storage spool. It was to be overcome by winding in strips of rubber tape at either side of the roll, so that the pressure of winding should be taken only at the edges and not on the central part where the plankton is deposited. Experiments with rubber tape were not a success, but the same effect has been obtained more easily by employing a wider banding of covering gauze, *i. e.* 8 in. instead of 6 in., and folding over an inch at each side. The folded edges lie between the sampling and the covering gauze and so take the pressure off the plankton lying between them, as shown in Text-fig. 14*a*. These edges are cut in slits every 4 inches, as shown in Text-fig. 14*b*. These are necessary to avoid the crumpling of the folded edges as they are wound round the spools, and are cut sloping forwards and outwards in the direction of motion so that the trailing points pass up more easily through the driving-rollers. These points are held down by drops of a solution of celluloid in amyl acetate. This arrangement, together with the use of the fusee which takes the tension off the silk as just described, has led to a great improvement in the condition of the plankton collected.

Brief reference should be made to another attempted improvement which was in use during part of 1937, but has since been discarded. It was introduced at the suggestion of Mr. C. E. Lucas. On the supply spool with the covering silk was wound a banding of cellophane. As the recorder worked the two bandings were wound off together and joined the sampling banding with the cellophane on the inside, thus preventing the plankton from coming in contact with the covering silk. This cut down the work of analysis almost by half, for without the cellophane it is always necessary to examine both the sampling silk and the corresponding area of covering silk, on account of some of the plankton always being transferred from the former to the latter. The cellophane was kept in position when the covering silk was removed, and so acted as a flexible "cover slip" through which the plankton could be examined under the microscope. It seemed a brilliant idea in principle, but it failed for an unexpected reason. It was found in practice that since its introduction, much of the plankton tended to be carried out to the sides of the silk banding. The reason for this is now clear. Without the cellophane the pressure of water in the tunnel causes some escape of water up through the silk bandings as they pass up between the driving-rollers, which have a gap between their central sections to avoid crushing the plankton. With the introduction of cellophane this escape was impossible, so the water was forced out at the sides either just before or just after the bandings passed the rollers; this flow of water to the sides carried some of the plankton with it. Reluctantly this innovation, which promised such a great saving of time in analysis, has had to be abandoned for the present; future attempts may be made to overcome its present drawbacks.

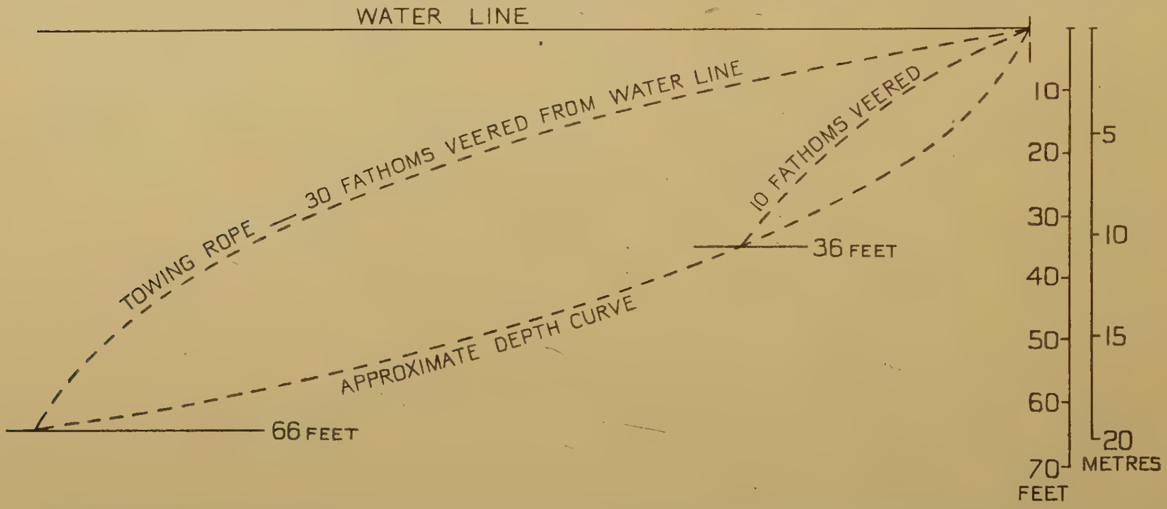


TEXT-FIG. 14.

METHODS OF WORKING AT SEA.

We have been extremely fortunate in gaining the kind interest and co-operation of so many shipping companies, and the willing and friendly help of their officers and crews in the towing of the recorders. Eight different companies are at present taking part (see "Acknowledgments" on p. 53), and the whole scheme is entirely dependent upon this great service which they generously put at our disposal.[1]

Each ship is provided with a small hand-winch, towing-rope, davit and block. These are described in the section following. The recorder, all ready for working, is sent to the ship in a strong box. It is arranged that the recorder shall be launched at some definite point, usually when passing some lightship, on leaving the coast and taken up again at some such point on reaching the other side of the North Sea. For example, on the Bremen line the recorder is put out at the Outer Dowsing Lightship and taken in at the Borkum or the Norderney Lightship; on the Rotterdam line the points are the East Dudgeon and the Maas Lightships. If weather conditions are unsuitable for running the machine on the outward voyage then it is run in the opposite direction on the homeward voyage. Instructions are given not to run the recorder in rough seas of force 6 and over, in fog when the ship may have to stop or go astern, or if herring-nets, which the instrument might foul, are lying across the path of the ship. In the latter case the instrument is taken in and re-launched after passing the herring fleet. The advisability of using the



TEXT-FIG. 15.—Graph kindly prepared by the School of Mine Design, H.M.S. *Vernon*, Portsmouth, showing the depths taken up by the plankton recorder with different lengths of towing rope of 0·255 in. diameter. The curve holds good for speeds between 8 and 16 knots.

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[1] No charge whatever is made by the companies for this service, but as a matter of routine, each time a traverse is made we pay £1 to the captain, asking him to distribute it as he thinks fit to his officers and crew who take part in the operations at sea—a small charge indeed when we consider that in return we get a line of observations right across the sea.

recorder is, of course, left entirely to the discretion of the captain. The instances of bad weather prohibiting the use on both the outward and return voyage are comparatively uncommon. On the Copenhagen line, which passes over a shallow patch at the south-west corner of the Dogger Bank, the instrument is raised 2 metres and lowered again after passing the possible danger-spot. When the instrument is first used one of our staff accompanies the ship to give a demonstration of its handling; after that the procedure is carried out as a matter of routine.

As the recorder is launched the ship slackens to half-speed, the instrument is lifted over the rail and the cable slowly veered out against the brake. A mark is placed on the cable at a point nine-and-a-half fathoms from the outboard end, and the rope is veered out until this is at the water surface ; the recorder is then swimming at the desired 10 metres.

Between 8 and 16 knots differences in speed make no appreciable difference to the depth at which the recorder swims. The machine takes up a position which is determined by the downward thrust of the diving plane and the backward thrust caused by the resistance to the water of the machine and its towing cable. With increased speed, within the limits above mentioned, both the downward and backward thrusts increase together in approximately the same proportion. If the ship reduces speed below 8 knots then the recorder will sink deeper. Whilst the recorder has been tested for stability up to a speed of 16 knots, a somewhat lower speed is preferable to reduce the strain on the mechanism ; the speeds of all the ships in the survey at present range between 9 and 15 knots. From trials carried out at speeds from 8–16 knots the Admiralty Department of Mine Design have kindly prepared the diagram reproduced in Text-fig. 15, from which may be estimated the depth at which the recorder will run for different lengths of towing cable, 0·255 in. diameter (that used in our survey), up to 30 fathoms veered from the water-line.

A reading of the ship's automatic log is taken when the recorder is launched and when it is hauled. From this we know (if the instrument for any reason has not been towed the whole distance between two lightships) how far it has run, and so can calculate the distance represented by each section on the gauze roll. The ships are asked to give check readings of their logs against definite points on their route (*e. g.* lightships), so that we can detect and make allowances for any errors and variations in the individual logs which may occur. The captain is provided with a log-sheet on which is entered all such particulars as positions and times of launching and hauling, log-readings and states of weather and sea. A discussion of the errors in log-readings due to changes in sea and tide will be found on p. 40.

After hauling, the recorder is placed in its box ready for collection and transport to the laboratory at the end of the voyage. In hauling, the speed of the ship need only be reduced if the sea is rough.

Equipment for the Ships: Wire Rope and Winches.

From the tests made at the Admiralty Department of Mine Design it was found that the pull on the towing-rope at a speed of 16 knots was approximately 10 cwt. Normally with our ships running at speeds of 10–13 knots this pull would be considerably less, but in conditions of rough sea it is possible that at times the pull may reach or exceed the estimated 10 cwt. for 16 knots. A breaking strain of 3 tons was decided on; but by selecting an aircraft cord, which is made of a much higher tensile steel than ordinary commercial rope, it was possible to keep down its size to a diameter of 0·255 in. An unforeseen failure occurred. On a third run across the North Sea the rope broke and a machine was lost. The broken end was examined in the laboratories of Messrs. British Ropes, Ltd., who were able to determine that the fracture was due, not to overloading, but to the development of fatigue through vibration. To overcome this difficulty three measures have been taken:

(1) Messrs. British Ropes have made a special rope for this work which is the same aircraft cord as before, but with the addition of a fibre core which has the effect of damping down vibration and so reducing the development of fatigue. The detailed specification of this rope is as follows: Drawn galvanized plough steel wire rope, 6/19 construction with a main fibre core, each wire 0·018 in. diameter; breaking stress 60 cwt.

(2) A special shock-absorber, in the form of a rubber compression block within a steel cylinder, was made to be fixed between the end of the rope and the machine. This has a further effect of damping down the vibration in the rope at the outboard end where it is likely to be greatest and where fatigue had previously developed. The shock-absorber is shown in Text-fig. 6, and is described in detail in '*Discovery* Reports', XI, p. 490.

(3) Between the towing-rope and the shock-absorber is shackled a double bridle (2 ft. 6 in. long) of the same specification as the towing-rope. This gives double strength at the point on the rope where fatigue is likely to develop. These double bridles are replaced by new ones after every crossing of the North Sea.[1] Their cost, eight shillings, is a small premium to pay for safety when the machine costs so much. After two or three runs, depending on the length of the route traversed, the outboard end of the main rope is shortened by two fathoms, so that its end, which is possibly fatigued, is discarded; after a further two or three runs the rope is turned end for end, so that the inboard end, not hitherto subjected to fatigue, may now be used; after the next two or three runs the rope is again shortened by two fathoms, and finally, on completion of eight or twelve runs, the rope is discarded.

The attention to the wire rope every two instead of three runs was introduced quite recently. With the precautions outlined above, except for the change just referred to, the recorders ran for well over 50,000 miles without further loss due to fatigue. But in the extended survey introduced last year (1938) we increased the length of tow on some of the lines, with the result that fatigue again developed and we lost two machines on the same night; in each case the rope was on its last run before replacement. The lines are now limited to an approximately 400 miles tow, and on these longer lines the ropes are attended to every two runs and scrapped after eight.

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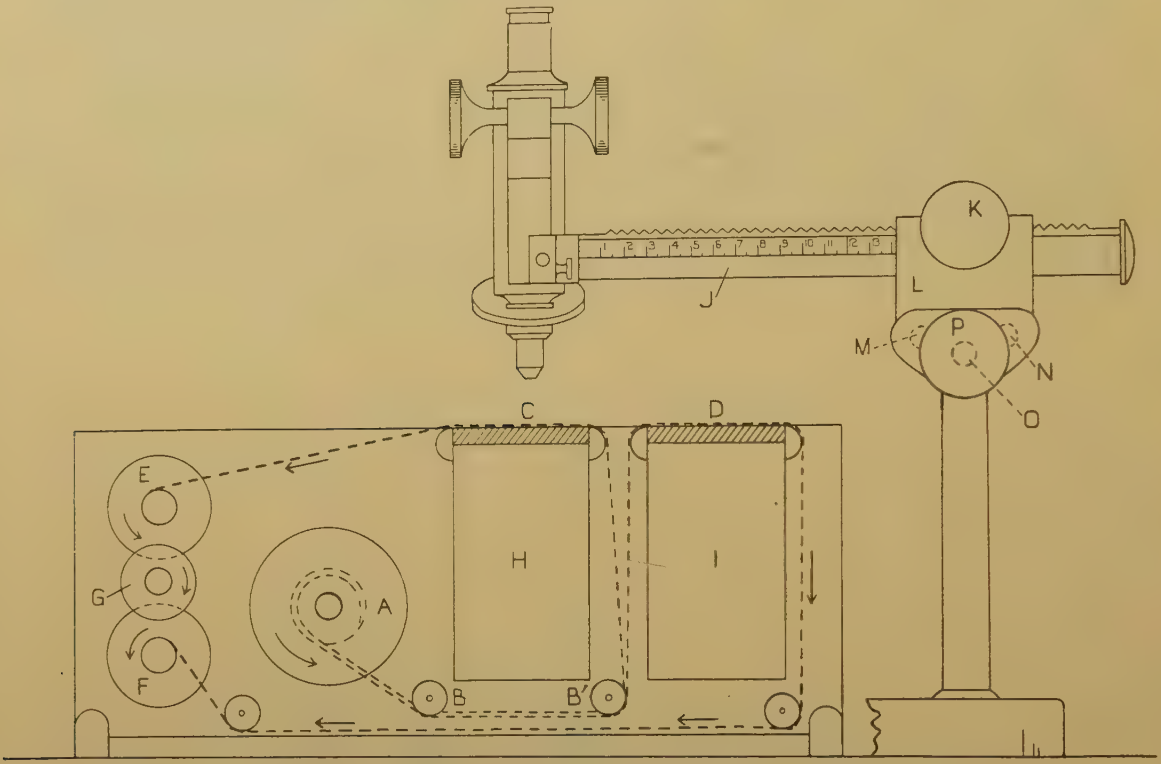
[1] Except on the short Hull-Rotterdam line, when they are replaced after every two runs.

Text-fig. 16.—Photograph of a set of plankton recorders and winches (specially designed for use with recorders on commercial ships) under construction in the College workshops for the extended survey of 1938.

Text-fig. 17.—The plankton recorder (ringed with white) in position for lowering away from the davit on the S.S. *Albatross* of the Argo Shipping Line (Hull to Bremen). The winch is seen behind the box used for the transport of the recorder to and from the ship.

Small hand winches were specially designed for the purpose; they have a two-speed gear so that they can be worked comfortably by one man or more quickly by two. These are shown in course of construction in Text-fig. 16, and as fitted to one of the ships in Text-fig. 17. A davit, with a 4-ft. radius to swing the recorder well clear of the stern of the ship, is mounted against the rail aft; this is placed in a position to allow the wire rope, passing through a block suspended from it, to have a straight lead astern from the winch.

The recorders and winches are now constructed almost entirely in the College workshops—see " Acknowledgments ", p. 53.



TEXT-FIG. 18.—Diagram of the stage and traversing microscope designed for examining the recorder rolls. For explanation see text.

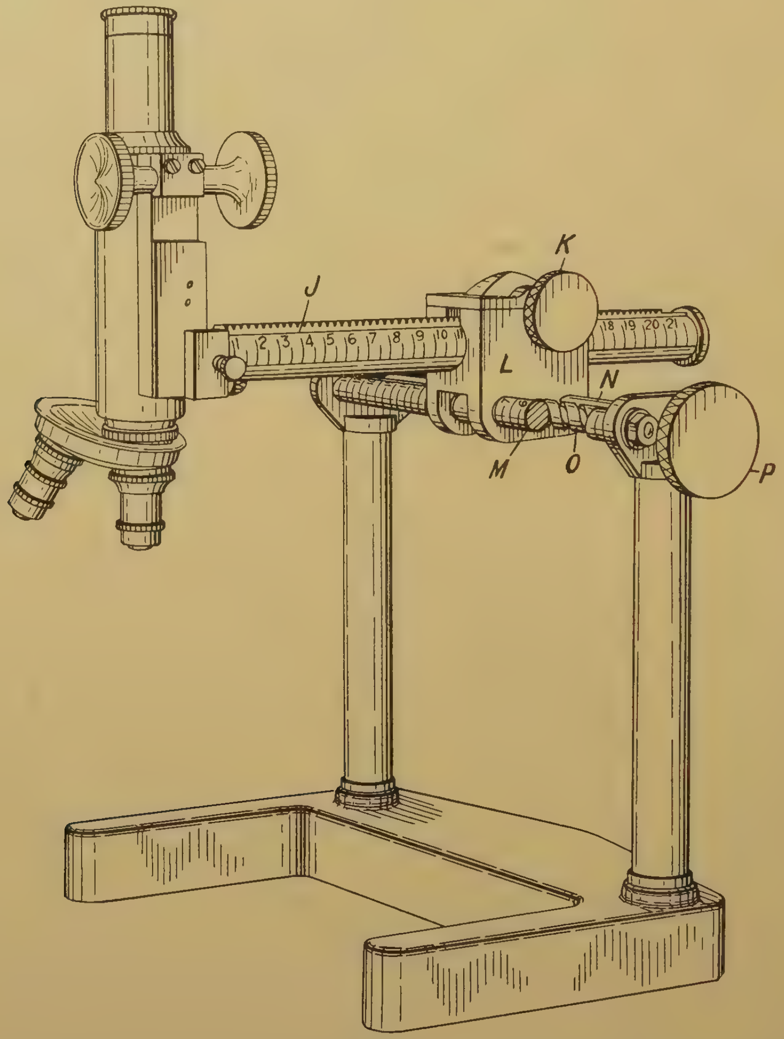
LABORATORY METHODS.

With the extension to the survey made last year (1938) a revised technique has been developed, employing different types of microscope and stage for the examination of zoo- and phytoplankton respectively. Since the reports immediately following this will deal with the years 1932–37, the present account will deal with the method then in use and the newer methods will be described, with certain modifications in equipment, when the 1938 results are published. It is likely that further developments of technique will occur.

At the end of a run the storage spool is taken out of the preservation tank of the machine and may be kept in formalin until required for analysis. Examination of the roll in these early years was carried out by unwinding it on a stage beneath a traversing microscope ; both were specially designed for the purpose, and are shown in Text-figs. 18 and 19. Text-fig. 18 shows the examination stage in diagrammatic section. The storage spool was mounted at *A*, and the two gauze bandings were led off round the rollers *B*, *B′*, passed up and separated, to the right and left, over the glass stages *C* and *D*. The gauze passing over the stage *C* leads on to the empty spool *E*, and that passing over *D* leads round a series of rollers to pass back under the whole frame to the spool at *F*. These spools *E* and *F* were geared to the handle at *G* ; when this was turned the two bandings were drawn apart, so that as a section of the graduated roll covered one stage, the corresponding area of the plain gauze covered the other. The plankton was thus exposed on the upper surfaces of the two gauzes as they lay over the glass stages. Mirrors at *H* and *I* reflected light up through the glass stages, so that the plankton on the gauze could be examined. Whilst in the first place the plankton is caught only on the graduated gauze, some of it is transferred to the surface of the covering banding. The glass stages were ruled into squares by intersecting lines to facilitate counting ; when using low-power lenses the squares on the glass showed through the gauze above them.

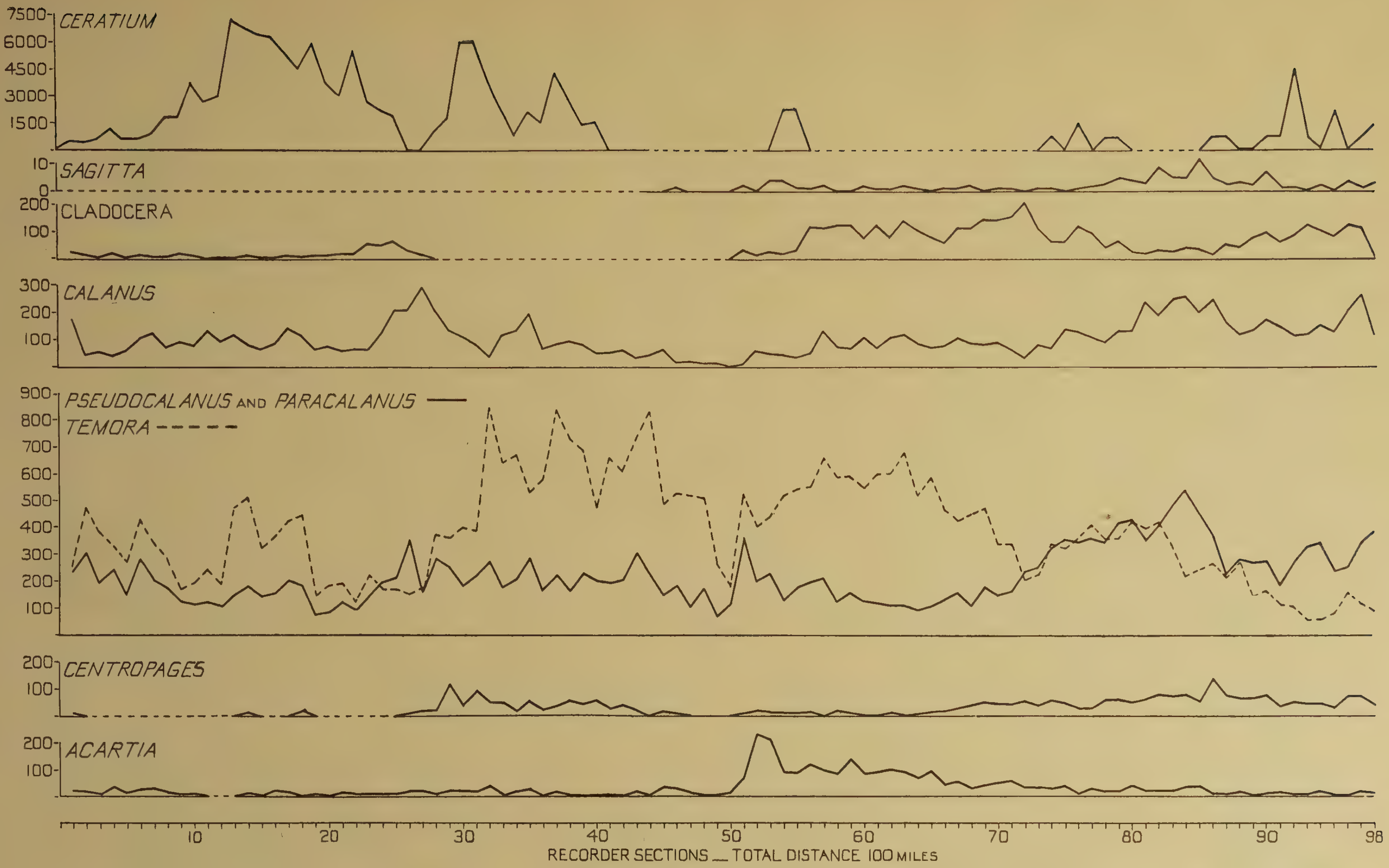
Text-fig. 19 shows the traversing microscope in detail. This is still used in the 1938 technique. A standard microscope tube is mounted on the arm *J*, which may be moved from left to right by a rack and pinion turned by the milled wheel *K*. The carriage *L* which holds the arm *J* is mounted to slide along the two rods *M* and *N* at right angles to *J*, and is moved backwards and forwards by a worm thread *O* turned by the milled wheel *P*. Thus by turning *K* and *P* the microscope may be made to cover any point of the examination stages *C* and *D*. The arm *J* and one of the rods *M* are marked with a series of numbered divisions, so that the position of the microscope objective over the stages may be noted at any time and then later returned to the same spot if required. The compound microscope body may be removed and replaced by a simple lens-holder for viewing larger objects if desired.

The larger and rarer organisms may be counted over the whole section and its counterpart of plain gauze. Smaller and more numerous organisms may be counted over selected areas and an estimate made of the approximate number on the whole section and its counterpart (see the next section on the interpretation of results). 1-in. and $\frac{2}{3}$-in. objectives are used for the examination of the majority of the zooplankton, and $\frac{2}{3}$-in., $\frac{1}{2}$-in. and $\frac{1}{6}$-in. for the phytoplankton. Formerly when an estimate had been made on the silk gauze the plankton was removed and stored in tubes numbered to correspond with the respective sections, so that it could later be referred to should it be desired to carry the analysis further in the light of subsequent events. The larger forms were picked off, and the remainder taken off with a safety-razor blade mounted in a handle. In the more recent (1937) technique the silk is cut into sections and the organisms are stored *in situ* on the silk, which is only used once. In the greater part of the earlier work the tubes were, in fact, always examined as part of the analysis technique ; for example, in the estimation of the Copepoda the totals (all species) were first of all estimated from a count on the actual gauze, but the identification of the different species was carried out by Mr. Rae from a tube examination of a proportion of the sections, as explained by him in ‘Bulletin’ No. 4. The percentage proportion occupied by each species was enumerated. In the new technique the copepod species are analysed on the silk itself.



Text-fig. 19.—The traversing microscope specially designed for use with the examination stage. The graduated rod *M* is cut to show the worm *O*. For further explanation see text.

As separate reports will be issued on the distribution of the phytoplankton, the Copepoda, and the remainder of the zooplankton, and as the methods of analysis



Text-fig. 20.—Typical specimen of a graph showing the analysis of a recorder roll from the North Sea. The record was obtained between lat. 57° 4′ N., long. 2° 0′ E., and lat. 55° 50′ N., long. 0° 5′ E. on 22nd June, 1931, at a depth of 10 metres during trials before the beginning of the actual survey.

of each of these groups is somewhat different, the detailed description of these different methods will best be dealt with in the separate reports concerned with each.

THE INTERPRETATION AND CHARTING OF RESULTS.[1]

The process of analysis results in a record of the varying numbers of the different organisms caught in each of the consecutive sections of the gauze. The distance of the sea traversed for every section of gauze exposed is obtained by dividing the total distance of the run by the number of sections exposed. If 50 sections have been exposed in a run of 100 miles, for most practical purposes each section may be said to correspond to a distance of 2 miles of sea ; actually, as will be shown presently, this is not strictly true, for each section will also sample a little of the water immediately preceding and following its particular 2 miles. But as a rule this effect may be disregarded (see below). Text-fig. 20 shows a graph of a typical record obtained in the North Sea. The analysis was made by Dr. G. T. D. Henderson and Mr. J. H. Fraser.

If one is merely making a study of the irregularity of distribution in different areas the results may be charted directly in the form of numbers per section, with an accompanying distance scale below, as has been done in the preliminary study of the unevenness of oceanic plankton (Hardy, 1936). If the machines are being used for a periodic survey of an area, it may be desirable to employ more refined methods of charting. The quantities of plankton recorded, both on different lines taken simultaneously and upon the same line at different intervals of time, should be strictly comparable. They may be made comparable by converting the number of organisms taken per section to the number taken per mile tow and the results (numbers per mile per section) graphed accordingly. In the 1932–37 survey this was done for zooplankton but not always for phytoplankton ; in the latter case the differences in numbers we are comparing are so great that such refinements would be of negligible consequence and an unwarranted labour. Since 1938 the silk rolls are cut into exactly 10-mile blocks, and all organisms recorded as numbers per 10-mile block, or as numbers *per mile* per 10-mile block.

We have above indicated that a statement that each section of the gauze represents, say, 1·5 to 2 miles of sea traversed can never be strictly correct. Each section of the graduated gauze covers exactly the area of the cross-section of the water-tunnel at its point of traverse. Let us suppose that the gauze banding is being wound on at such a rate that any point upon it crosses the water-tunnel in the same time as the machine has travelled 1 mile through the sea. In Text-figs. 21 to 24 let the horizontal lines tu and $t'u'$ represent the roof and floor of the water-tunnel or their continuations, and let A, B, C, D and E be points in the sea half a mile apart along the path of the water-tunnel, which is being towed forward. Let XY be a section of the moving gauze banding which takes a path across the water-tunnel, represented by its dotted continuation. In Text-fig. 21 let *X* begin to cross the tunnel just as the point *A* in the sea crosses the path of the gauze. Now let *X* be wound across the water-tunnel in the same time that the machine is towed through a mile of sea, so that in Text-fig. 22 *X* will have reached the position

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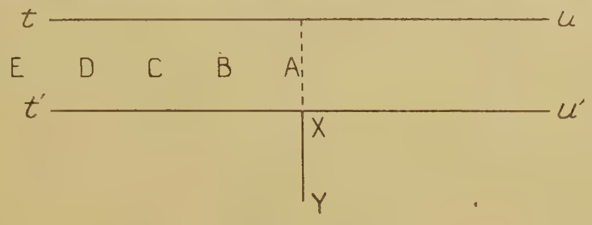
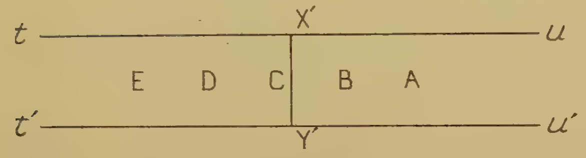
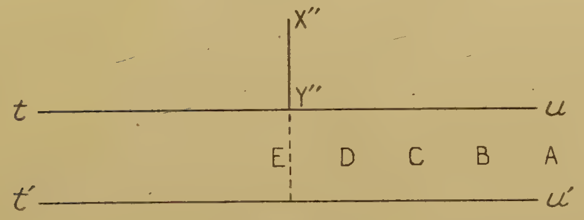
[1] Part of this section has been reprinted with the permission of the *Discovery* Committee from the author's paper on "The Continuous Plankton Recorder" in '*Discovery* Reports', XI.



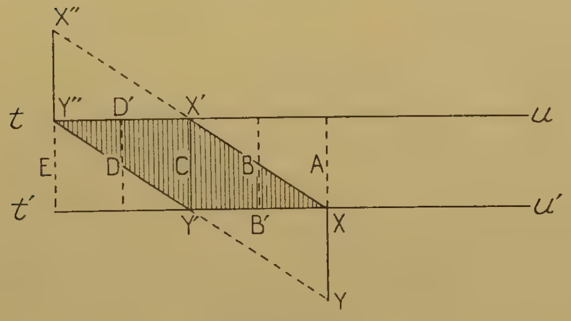
TEXT-FIG. 21.



TEXT-FIG. 22.



TEXT-FIG. 23.



TEXT-FIG. 24.

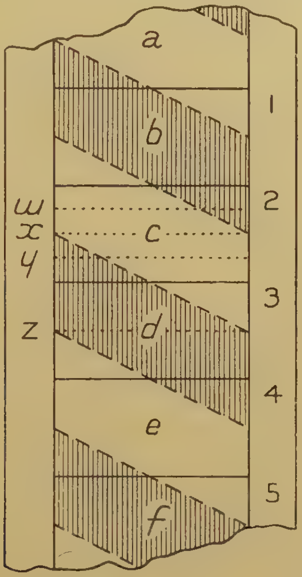
X′ when *C* is passing through the gauze; *Y* will now be at *Y′*. In Text-fig. 23 the section *XY* has wound completely through the tunnel to *X″ Y″*, and *E* will be passing through the gauze of the following section.

In Text-fig. 24 let us combine Text-figs. 21–23. The sea *ABCDE* is really stationary, the tunnel moving from right to left, and *XY* in relation to the sea follows the path through *X′ Y′* to *X″ Y″*. *A*, *B*, *C*, *D* and *E* are at half-mile intervals.

The water strained by the section XY as it crosses the tunnel will be taken from the consecutive half-miles of sea in proportions corresponding to the areas covered by the parallelogram $Y''X'XY'$. The triangle $BB'X$ is one-eighth or $12\frac{1}{2}\%$ of the area of the parallelogram ; so is the triangle $Y''D'D$. Thus, of the water filtered by the section XY, 75% will come from the mile of sea BD and $12\frac{1}{2}\%$ from the preceding half-mile AB and $12\frac{1}{2}\%$ from the following half-mile DE.

Text-fig. 25 shows diagrammatically this relation of the sections on the gauze to the units of distance travelled if a point on the gauze crosses the water-tunnel for every unit of distance that passes the machine. If the units of distance are miles, the proportions of the water filtered from each mile may be represented by the parallelograms a, b, c, d, e, f, . . . , which lie across the rectangles 1, 2, 3, 4, 5, . . . , which in turn represent the sections on the gauze. As seen in Text-fig. 25, 75% of the water filtered by section 1 comes from mile b and $12\frac{1}{2}\%$ from the second half of the mile a, and $12\frac{1}{2}\%$ from the first half of the mile c. Now if we examine only the plankton deposited along the dotted lines crossing the middle of the sections 2 and 3 at x and z, that on each line will be a sample representative of the miles c and d, unadulterated by proportions of the plankton from the miles b and d and c and e respectively. If the organisms we are estimating are small and numerous, a single-line examination traverse may suffice to give an estimate of the number per mile. If we examine an area on the section 2 lying between the dotted lines w and y, which lie at the quarters of the section, then the plankton will have come from water of which 87·5% belongs to the mile c and only 6·25% to the last quarter of the preceding mile b, and 6·25% to the first quarter of the following mile d. Similarly, if we examine one-quarter of the section, with the line x down its middle, the plankton will have come from water of which 93·75% belongs to the mile c and only 3·125% to the last eighth of the preceding mile b, and 3·125% to the first eighth of the following mile d. Usually the plankton sample deposited on each section is rich enough to render a traverse examination of a fraction of the section sufficient to form the basis for an estimate of the whole. We may say that, for all practical purposes, the plankton estimated on each section does represent the plankton belonging to the mile (or whatever distance it is) which is known to have passed the machine during the time that a point upon the gauze has crossed the tunnel, *i. e.* the distance found by dividing the length of the run by the number of divisions exposed. It will, of course, be realized that Text-fig. 25 shows a geometrical representation of the proportion of the water filtered by each section ; it does not mean, for example, that in section 2 the top right-hand corner only will filter water from mile b, but that the proportions of the water of b and of c filtered along a whole line such as w will be equal to the proportions of the line that cross respectively the areas b and c shown in the figure.

In the interpretation of the charted results we must take into account certain sources of error. Let us return to our example of 50 sections having been exposed in a run between two points known to be 100 miles apart. The results will be charted as if each section represented a distance of sea traversed of 2 miles, whereas actually there may have been a slight variation in the ratio of the silk exposed to the distance covered in different parts of the course. If during the first half of its course the ship encountered a strong tidal stream against it, and in the latter half of its course a stream in its favour, then more water will have passed the machine in the first half of the journey than in the second. Whilst the ratio of water passed per section remains constant, there will be a smaller ratio of miles per section during the first part of the course than over the second. Of this we shall usually have no knowledge, and a patch of organisms lying, say, on section No. 25 which we should chart as being half-way along the course will actually have lain not quite so far along. These errors will not be great, but it must be understood that any one part of the graph may actually have been a few miles to the right or left of the position shown. (See the discussion regarding Table I below.)



TEXT-FIG. 25.

If the record is taken from one fixed point, such as a lightship, to another, as should normally be the case, we know the exact distance covered by the record, but sometimes the recorder may have to be hauled up at some point along the course on account of fog, rough weather or perhaps herring-nets being in the way, and the position of hauling given as so many miles by log from the starting-point. In this case again the position of hauling can only be regarded as accurate to within a few miles. Latterly, by getting the ship's officer concerned to give us log-readings when passing various fixed points, such as lightships *en route*, we have been able to make some check on the accuracy of the logs and make corrections. Since this information was supplied to us we have 16 examples of the variations in the mileage, due to different conditions of sea and tide, recorded by the automatic log of the S.S. *Dewsbury* in travelling over three sections of the Rotterdam line (Table I). We see that over a total distance of 132¼ miles the error was once as much as 13¼ miles, or 10% ; on an average it is ± 5½ miles, or ± 4·0%. The errors in other parts of the survey will rarely be as large as these in this shallow part of the southern North Sea, where the tidal streams are particularly effective. The differences in the log-readings and the actual distance in different parts of the course due to changes in sea and tide show clearly how positions on our graphs may actually lie several miles to the right or left of their true position, as explained in the paragraph above.

Sometimes a recorder may work correctly for part of the course, but then stop winding on because of some mechanical failure. The principal causes for such failures are discussed later on p. 52. In order to make use of this valid part of the record, and chart the results, we must make an estimate of the distance travelled by the machine before the failure occurred. This we may do approximately, since we know how many divisions of the silk roll wound on before the stoppage, and we can obtain an estimate of the ratios of miles per division which are known for a number of previous runs of the machine. In plotting the estimated position of the end of the valid part of the record we must remember that it again can only be regarded as an approximation.

TABLE I.—*Variations in Mileage Recorded by Ships Log on the Rotterdam Line.*

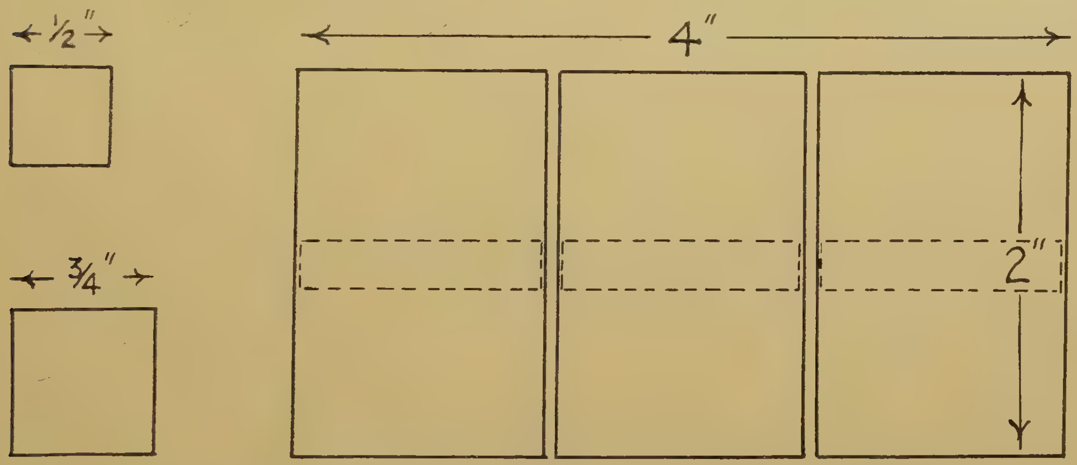
Record number.	From E. Dudgeon L.V. to N. Haisbro L.V. (29½ miles).	From N. Haisbro L.V. to Newarp L.V. (16 miles).	From Newarp L.V. to Maas L.V. (87¼ miles).	Over total distance (132¾ miles).	Percentage error.
65	+1½	0	+3¾	+5¼	+3·9
72	+4½	+5	+¾	+10¼	+7·7
73	−1½	0	−1¼	−2¾	−2·1
76	+2	+2	−8¼	−4¼	−3·2
77	0	−1½	−1¼	−2¾	−2·1
79	−3	−3½	+2¾	−3¾	−2·8
80	−2	−3	−1¼	−6¼	−4·7
81	+½	+2	+5¾	+8¼	+6·2
82	+5½	+5	+2¾	+13¼	+10·0
83	−2½	−1	+1¼	+2¼	−1·7
84	−3½	0	−¼	−3¾	−2·8
85	−2½	0	−¼	−2¾	−2·1
86	0	+1	+¼	+1¼	+0·9
87	−3½	−2	−3¼	−8¾	−6·6
88	−3½	−2	−3¼	−8¾	−6·6
89	+4½	+2½	−8¾	−1¾	−1·3
Average :	±2½	±2	±2¾	±5½	±4·0%

The scale of analysis and the degree of detail in plotting the results are dealt with in a subsequent special section entitled "Scale of Working" on p. 45.

THE CATCHING POWER OF THE MACHINE.

Throughout the survey a standard mesh silk gauze (bolting silk) of 60 threads to the inch has been used.[1]

The opening of the water-tunnel in the front of the recorder is very small compared with the area of its cross-section at the point where the filtering gauze crosses it. From the beginning of the survey in 1932 to the middle of 1937 the front opening was ¾ in. sq.; it was then reduced to ½ in. sq., as explained in the next section, when the scale of working was altered from 1·5–2 miles per section to approximately 5 miles per section. The relationship of the size of the two openings to that of the cross-section of the tunnel at the gauze is shown in Text-fig. 26. The area of the gauze, allowing for the obstruction of the vertical bars behind it and the rollers which they support (shown in broken line in the figure), is thirteen times as large as the cross-section of the ¾-in. sq. opening, and twenty-nine times as large as that of the ½-in. sq. opening. This ratio of size of filtration area to the opening is very much larger than that in an ordinary tow-net. In the standard international net (Ostenfeld and Jespersen, 1924), which has sides of length 200 cm. and a circular opening of 50 cm. diameter, the area of gauze is only nine times that of the opening, and in many tow-nets the ratio is less. Further in ordinary tow-nets, *i. e.* apart from the Hensen net, which



TEXT-FIG. 26.—A comparison between the areas of the ¾ in. and ½ in. square openings to the water-tunnel in front and the area of the cross-section of the water-tunnel where it is traversed by the collecting gauze. The rollers behind the gauze are shown in broken line.

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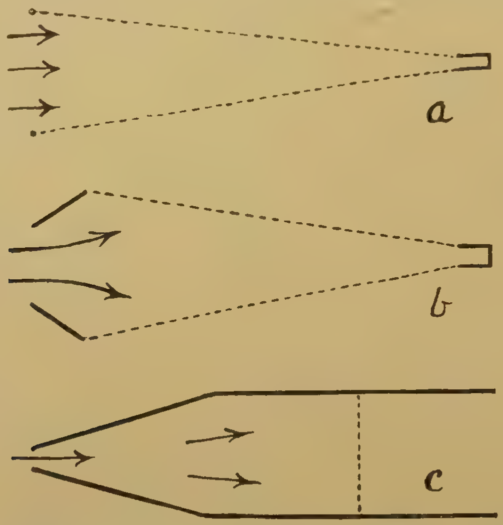
[1] Supplied by Messrs. John Staniar & Co., of Manchester, and termed by them: "Quadruple extra heavy quality double twist Swiss silk grit gauze No. 60."

first employed the principle of the reduced opening, the actual column of water confronted by the filtering surface is of the same cross-section as that of the opening. It is this ratio of 1 : 1 which should really be compared with the ratios of 1 : 13 or 1 : 29, in the case of the recorder openings of ¾ in. sq. and ½ in. sq. This relationship is illustrated in Text-fig. 27. In the recorder too, it will be noted that the silk gauze is stretched across at right angles to the column of water, whereas in a tow-net the gauze makes an acute angle with the line of water flow.

The small opening of the recorder, widening gradually to a so much larger tunnel, ensures that the speed of water flow at the gauze will be greatly reduced from that of its entry into the recorder, and also ensures that all the water entering the tunnel will pass through the gauze, unless its filtration is cut down by an unusually heavy deposit of plankton. The effect of clogging by plankton is dealt with under limitations of method on p. 47.



Text-fig. 27.—Diagram comparing the relation of opening to filtration surface in (*a*) ordinary tow-net, (*b*) Hensen net, and (*c*) plankton recorder.

Experiments have been made in which currents of water of speeds up to 14 knots have been made to flow into the opening of an exact replica of the recorder water-tunnel immersed in water in a tank. A constant force of water was obtained by double hosepipes siphoning water from a large container at a height of some 20 feet to a watertight junction piece passing the water to the recorder tunnel in the tank at ground level. A scale was provided to measure the volume of water taken from the container and the speed of flow measured with a stop-watch. It was found that for both the ¾ in. sq. and ½ in. sq. openings the presence of the gauze made no difference to the flow of water through the tunnel at speeds up to 14 knots; *the rate of flow was the same with and without the gauze.* Thus we know that all the water presented to the opening of the water-tunnel passes through the gauze unless it is heavily clogged with plankton. As shown on p. 47 it requires a very heavy sample of plankton to reduce the flow by 25%. When the recorder is being actually towed the flow of water will be assisted by the form of the exit which is placed behind the body under the streamlined tail, where the passing water will produce a " suction " effect.

The experiments further showed that the volume of water per second flowing through the gauze is directly proportional to the area of the opening at the front of the tunnel, if that opening is small. Four different sizes of aperture were used with the force of water (approximately that of a 14-knot current) kept constant. The results are given in Table II, and if plotted, give practically a straight line relationship between rate of flow and area of aperture.

For every mile the recorder is towed the following quantities of water, theoretically will be filtered for the two openings, provided excessive clogging of the gauze does not occur :

¾ in. sq. : 23·75 cu. ft. or 0·67 cu. m.
½ in. sq. : 10·55 cu. ft. or 0·30 cu. m.

TABLE II.—*Rate of Filtration in Relation to Size of Front Aperture with a Constant Force of Water approximately equal to that encountered when Towing at* 14 *knots.*

Area of aperture in sq. in.	Times, in sec., taken for a flow of 50 litres.	Average rate of flow in litres per sec.
0·56	19·8	
(=¾ in. sq.)	19·8	
	20·0	2·5
0·25	42·8	
(=½ in. sq.)	43·0	
	43·0	1·16
0·16	67·2	
	70·0	
	69·0	0·73
0·125	82·4	
	83·0	0·6

An idea of the catching power of the machine may be gained from the following table, which expresses the numbers taken per 1 mile tow of a selected number of organisms when the ¾ in. sq. opening has been used. The figures are maximum numbers taken from the survey in the southern North Sea :

Diatoms	*Rhizosolenia styliformis*	>50,000
	Biddulphia sinensis	>50,000
Dinoflagellates	*Ceratium*	>200,000
Chaetognatha	*Sagitta*	457
Cladocera	*Podon*	503
	Evadne	1633

Copepoda	*Calanus finmarchicus*	168[1]
	Pseudocalanus elongatus	1450
	Temora longicornis	1040
	Centropages	390
	Acartia	500
Amphipoda	*Proto pedata*	47
Pteropoda	*Limacina*	980
Echinoderm larvae		3240
Fish eggs		7
Post-larval fish		20

The above figures illustrate its capacity ; a typical fluctuation in numbers is shown in the specimen graph in Text-fig. 20.

It is clear that no one grade of silk gauze can effectively sample the whole range of plankton organisms found in the sea. Our present standard mesh of 60 threads to the inch was chosen as one likely to give a fair representation of the zooplankton organisms, such as Copepoda, Cladocera, Pteropoda and Chaetognatha, and at the same time give a clear indication of the areas of greater abundance of the larger phytoplankton forms, such as *Rhizosolenia*, *Biddulphia* and *Phaeocystis*, which are known to be of such economic importance in relation to the herring fisheries. There is no doubt that the 60-mesh silk lets through large numbers of the smaller organisms—but actually in practice it is found that many of these, when abundant, are retained in sufficiently large numbers on the meshes to enable their denser concentrations to be charted. A full consideration of this matter will be found in the report on the phytoplankton results by Mr. Lucas, which follows this introductory paper. As already stated it is hoped later to introduce, together with the 60-mesh silk, a narrow strip of finer mesh gauze to give a better representation of the smaller forms. Trials have already been made, but all the technical difficulties have not yet been overcome. As is well known, still smaller forms will pass through the finest gauze available.

The machine has an upper limit to the size of the organisms it can sample, as well as a lower limit, and exceptionally large organisms may fail to pass up the exit slot and be found on the last section.

It is a feature of the method that smaller samples are collected than by the use of the ordinary tow-net, but ones large enough to show the important differences in the abundance of the plankton. More often than not the tow-net yields samples, the contents of which can only be estimated in the laboratory by counting a very small fraction and making an estimate. The tow-net sample to begin with is taken from a confined area of sea, perhaps not more than a quarter of a mile tow when using a fine or medium silk. Thus by the tow-net method there may be two large sources of error in estimating the quantity of plankton in the area examined. The sample itself may not truly represent the area as a whole owing to the patchiness of the plankton ; then, after having taken so large a sample, there is the laboratory error in taking the fraction for examination. In the stempel pipette method, or other means of fractioning, all organisms may not be taken up in their true proportions. The recorder method takes a smaller sample over a wider traverse of sea, and the sample is deposited on the gauze by the sea itself so that the organisms are estimated in the proportions they were caught in. The gauze section represents the " telescoping " of the plankton in a long volume of sea into a small two-dimensional space for the convenience of examination. If each section is regarded as a sample, we may say that the recorder method presents us with a large number of small but representative samples spread over the whole line of the traverse instead of a few large tow-net samples taken at intervals.

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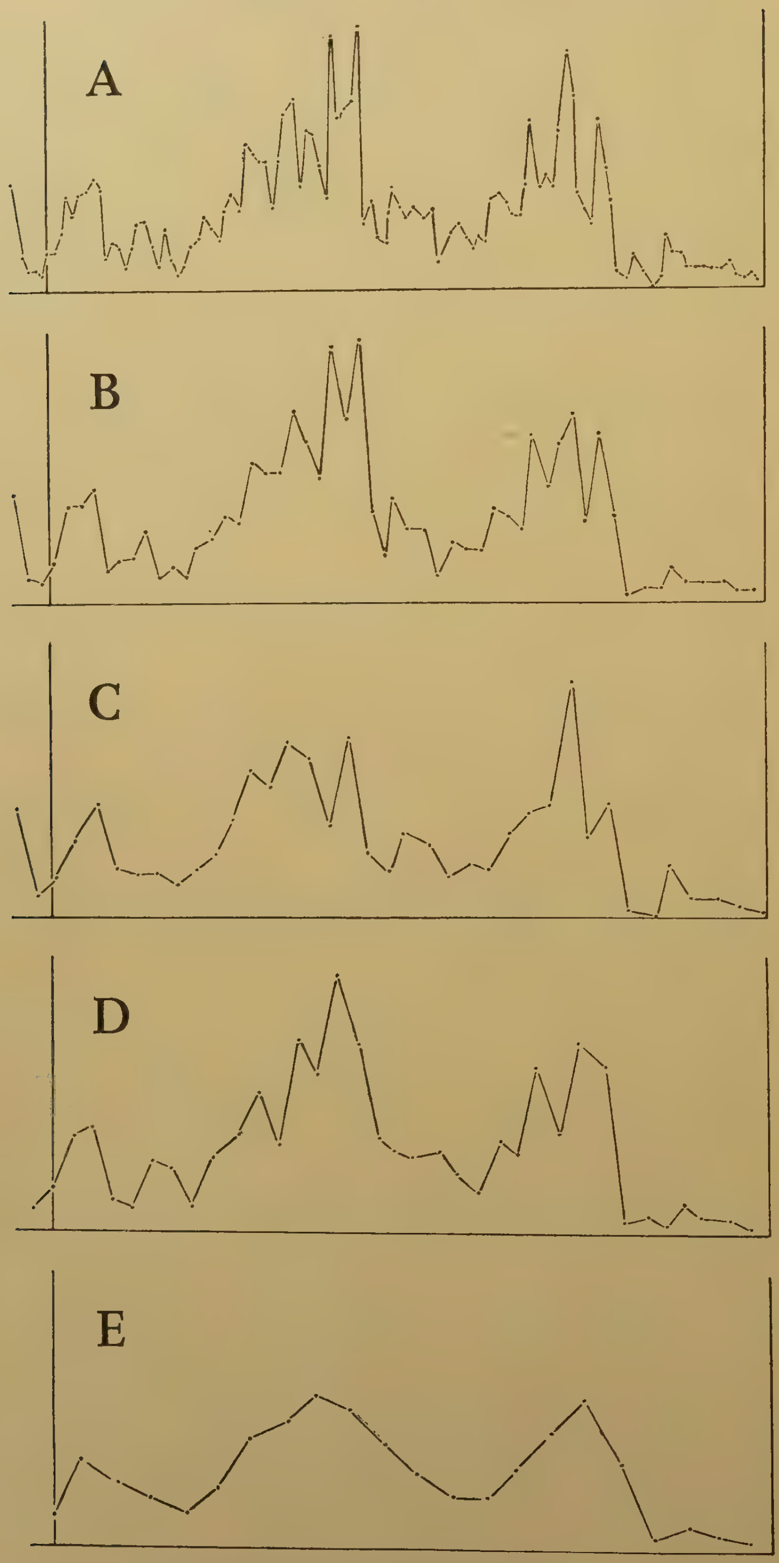
[1] The numbers of *Calanus* in the southern North Sea are very low compared with more northern waters.

The above is not intended to imply that it is considered that the recorder has superseded the tow-net as a general method of plankton research ; it is rather to be regarded as a supplementary method. There are clearly many classes of work that can best be served by the tow-net ; the limitations to the recorder method are discussed in a special section on p. 47.

Scale of Working.

In such an extensive survey, when keeping up to date with results is the essence of success, and when the process of analysis is such a long and laborious task, a consideration of the scale of working is of the utmost importance. In the first years of the survey we worked on a propeller setting giving a ratio of 1·5 to 2 miles per 2 in. section of gauze banding. We worked an analysis for each section. It was important at first to err on the side of refinement, so that we should know the usual extent of unevenness in distribution, and then be in a position to consider broadening our degree of working as much as we reasonably could ; had we started with a coarser degree of treatment we should have had less idea of how near to reality our results were. This is well illustrated by a series of graphs of total Copepoda prepared by Mr. Rae in Text-figs. 28A to E. Each represents the same record between the Outer Dowsing and Borkum Lightships (Hull-Bremen route) on 8th June, 1932. Graph A shows the result of plotting the number of Copepoda for every section, and Graph B that for every other section. They show a fair agreement. Graph C shows the result obtained by plotting for every third section, starting with the first section. Graph D also shows the result of plotting for every third section *but starting with the third section.* Quite a different result is obtained. It shows clearly that to cut down analysis to less than every other section would, for such organisms as the Copepoda, largely falsify the results of the survey ; the patterns of distribution obtained would largely depend on the set of sections selected. It also emphasizes what very different results must be obtained in a plankton survey with tow-net stations at considerable intervals apart ; the picture of distribution will be greatly modified according to the position of the stations. For a further discussion of this matter see the subsequent paper by Mr. Lucas, where he gives an example from the phytoplankton. Text-fig. 28E shows a graph



TEXT-FIG. 28.—For explanation see text, p. 45.

prepared by taking the average of groups of five sections together. This gives a result which compares reasonably closely with that obtained by plotting every section; but it entails, of course, the same amount of labour in analysis. Five sections together represent a distance of up to 10 miles.

Since the middle of 1937 we have been working on a propeller-setting giving approximately 5 miles per section and analysing the plankton for two sections together; we are now, in fact, working on 10-mile blocks. The collection of plankton is continuous; no part of the line is left out; the result is similar to that obtained by averaging groups of five sections on the old setting, and bears the same relation to the former more detailed method of working as does Graph E to Graph A. With the increased ratio of 5 miles per section the aperture at the front of the water-tunnel was reduced from ¾ to ½ in. sq., so as not to increase the quantity of plankton on sections above what it was before, and so prevent an increased error due to clogging. For small apertures, ¾ in. sq. and less, the flow of water through the gauze is directly proportional to the size of the aperture, as was demonstrated in experiments described in the previous section.

The scale of working adopted and the method of charting used in each piece of work will be stated in each of the papers dealing with different aspects of the survey.

LIMITATIONS OF THE METHOD.

To every method of plankton collection there are limitations; to the continuous plankton recorder method there appear to be two major disadvantages. Firstly, in regions of very rich plankton the filtration and catching power of the machine will be reduced by the clogging of the silk. This difficulty applies to all ordinary tow-nets, but perhaps to a lesser extent, because the greater part of the catch is carried back into the bucket; on the other hand we have seen on p. 42 how much greater is the ratio of filtration area to that of the opening in the recorder as compared with a tow-net. When carrying out laboratory experiments on water flow through a recorder tunnel (see p. 42) it was possible to make some estimate of the effect of clogging caused by zooplankton organisms. Plankton was added to the water stream until it was found that the rate of flow through the recorder with the ¾ in. sq. aperture was reduced by 25%. The plankton on the gauze was then estimated and found to be as follows:

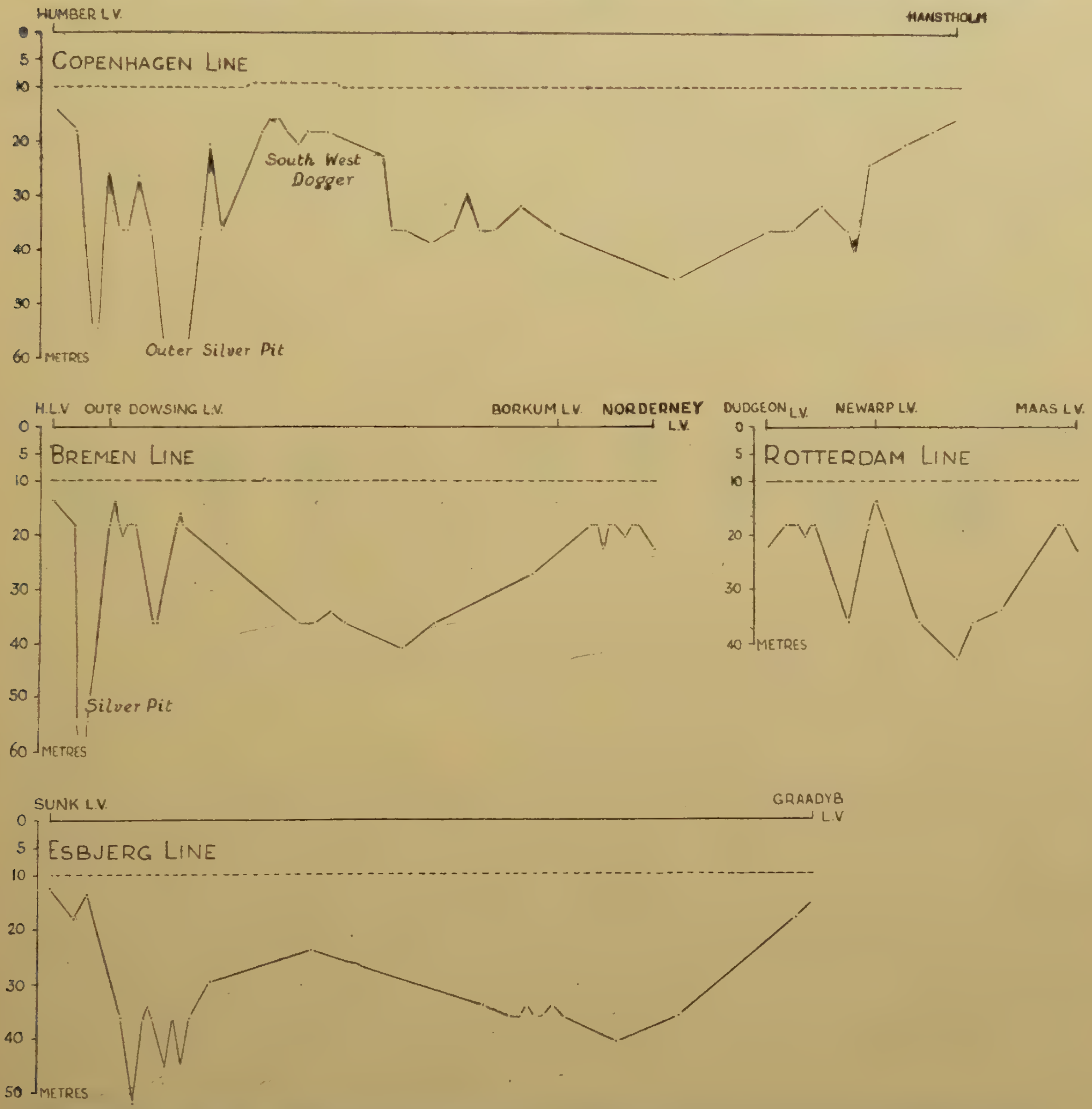
Calanus	320
Other copepoda	4240
Sagitta	120
Cladocera	440
Decapod larvae	40
Fish eggs	60

These are numbers much in excess of our usual summer maxima and they would clearly cause much less reduction in filtration in the case of the ½ in. sq. opening now in use. With dense phytoplankton the clogging is likely to be more serious. The method of estimating the effect of clogging on filtration has only just been devised, and it is hoped that before long a special study of reduction in filtration caused by different types of plankton will be made and published in a subsequent 'Bulletin'.

Whatever the effect of clogging, it is perhaps, not so serious a limitation as it may at first sight appear. Whenever organisms are taken in very large numbers one must realize that, but for the reduced filtration, even very much greater numbers would be taken; the peaks on the graphs made from records should be higher than they actually appear. The principal source of error will relate to the rarer forms which, when the filtration is reduced by the abnormal abundance of some commoner species, will be taken in even smaller numbers or not at all. On the other hand, smaller forms, which usually pass through the meshes of the silk, may be retained in larger numbers if the openings of the net are much reduced by clogging. It must be remembered, however, that continually there is a fresh surface of gauze being presented to the water-flow as the thick deposits of plankton pass on into storage. As soon as the dense concentration is past the reduced filtration will be rectified. It has been suggested that the propeller might have been placed inside the water-tunnel instead of on the outside of the machine, so that the gauze would be wound on in direct ratio to the amount of water passing through the gauze. Under such an arrangement the machine would, of course, serve an entirely different function; in our survey we are concerned with comparing the relative quantities of plankton in different units of distance of sea traversed; the silk must wind on in direct relation to the water *passing the outside* of the machine. When we find the plankton of one unit of distance very much higher than that of another unit, as explained above, we must realize that it is really somewhat higher than we are actually recording. The graphs obtained clearly show that the method is capable of recording a very big range of differences in abundance.

The second and more serious limitation is that due to the use of only one instrument making a record at a uniform depth when some organisms are carrying out diurnal vertical migrations. Whilst there is clearly evidence of the influence of vertical migration upon the records taken in deep water areas in the Southern Ocean (Hardy, 1936*b*), the evidence from the shallow water region of the southern North Sea, sampled in our survey 1932–37, would indicate that vertical migration has little influence upon the results. The recorder is run at a standard depth of 10 metres (except when it passes over the south-west patch of the Dogger Bank and is hauled up to 8 metres for a short period). The paths of the recorders in relation to soundings along the Copenhagen, Bremen, Rotterdam and Esbjerg lines are shown in Text-fig. 29; it is seen that the recorder runs, on an average, in a fairly mid-water position. A depth of 10 metres was chosen as being the most likely to give consistent results in relation to both phyto- and zooplankton. Text-fig. 30 shows the theoretical average vertical distribution of *Calanus* in the

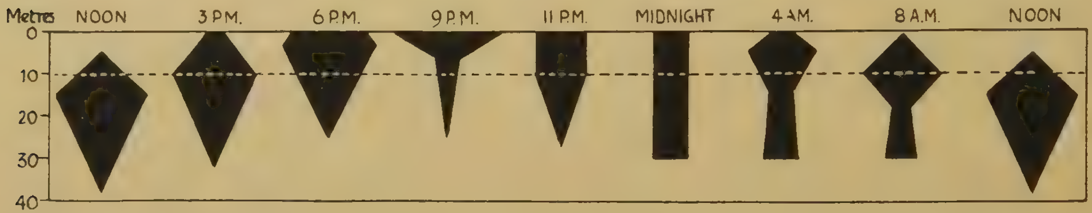
Plymouth area as deduced by Russell (1927); it is seen that if sampling is made along a line drawn at 10 metres, representing the path of the recorder, it will give



TEXT-FIG. 29.—Diagrams representing vertical sections through the sea along the Copenhagen, Bremen, Rotterdam and Esbjerg lines. The vertical scale (in metres) is greatly exaggerated. The surface of the sea is shown as a straight continuous line, the path of the recorder as a broken line, and the sea-bed by lines connecting points representing soundings along the routes taken by the ships.

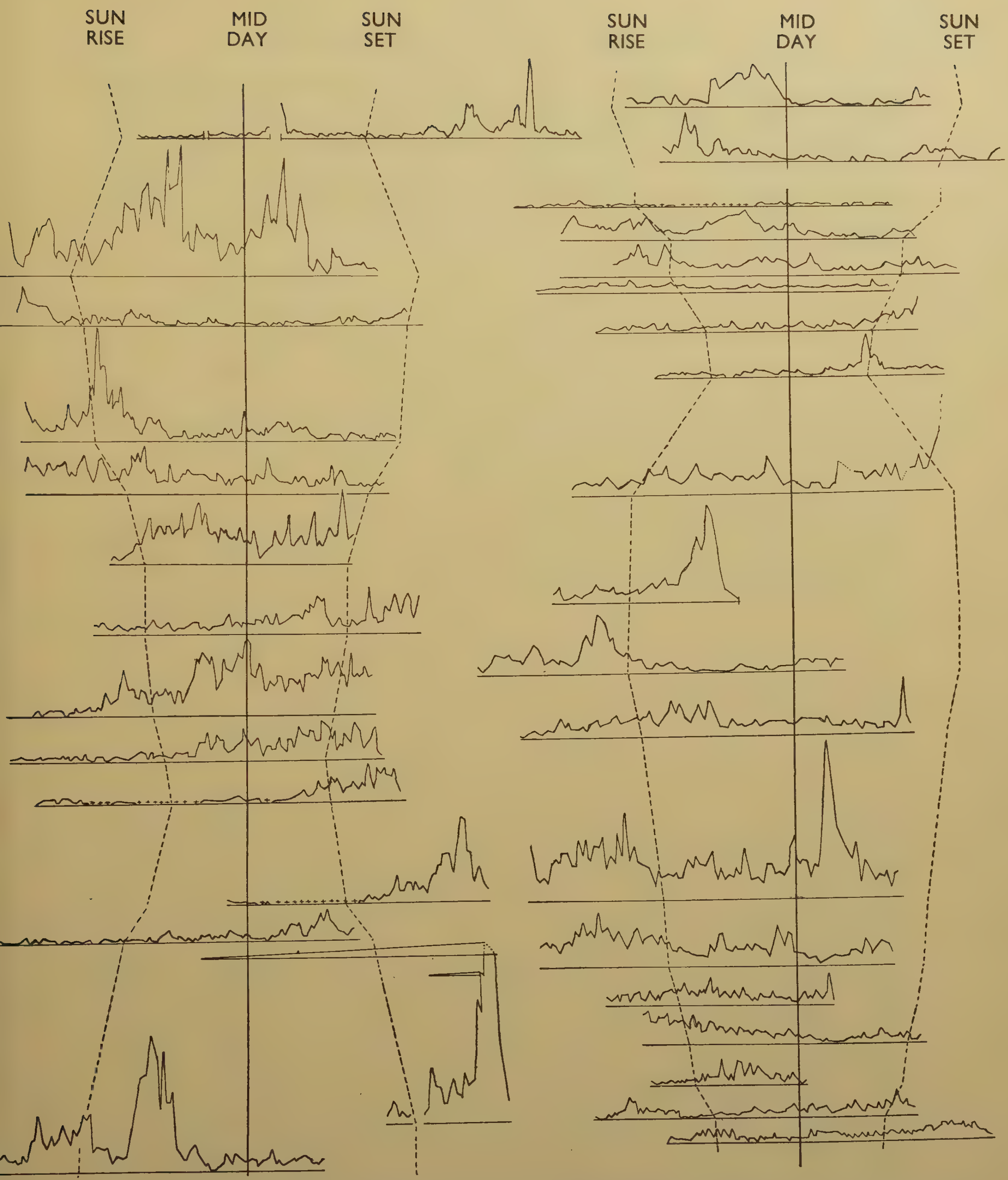
the most consistent results throughout the twenty-four hours. We may form some idea as to whether diurnal vertical migration is having a marked influence upon the results of our survey by the method shown in Text-fig. 31 ; here we have arranged all the graphs for total Copepoda taken during 1932, 1933 and 1934 along the Bremen line, one below the other in such positions that the midday points on each graph lie one below the other on a vertical line drawn down the figure. The times of sunrise and sunset are shown as broken lines. If diurnal vertical migration was seriously affecting our results we would expect to see larger quantities being taken in the periods of darkness, *i.e.* at the two ends of the lines; this, in fact, we do not see: there are as many peaks on the curves in the periods of daylight as in the periods of darkness. The influence of vertical migration is discussed in greater detail in relation to the Copepoda by Mr. Rae in 'Bulletin' No. 4.

We may well find that vertical migration will have some effect on the lines over deeper water in the northern area of our recently extended survey ; this is being carefully watched. An ideal arrangement would be the towing of two or more machines one below the other at convenient depths apart ; this is impracticable in a survey carried out by commercial ships and also, at present, on grounds of cost. A valuable idea for overcoming the effect of vertical migration was proposed by the late Mr. J. O. Borley ; he suggested that a device should be fitted which would continually alter the angle of the diving plane so that the machine would take an undulating path through the water. For every mile that it was towed forward it might be made to sink to some 30 or 50 metres and rise again towards the surface ; the machine would traverse the sea in a series of regular undulations, and so each section of the silk would sample the plankton over a considerable range of depth. Initial experiments in this direction have already been made. There are still a number of difficulties to be overcome, but it is hoped that before long this device will be successfully incorporated in the design of future machines.



TEXT-FIG. 30.—The theoretical diurnal vertical distribution of *Calanus finmarchicus* in the Plymouth area as deduced by Russell (1927) from actual observations. The figure is taken from that of Russell with the addition of the broken line at 10 metres to represent the line of sampling of the plankton recorder.

Another disadvantage of the method, but one which has now been largely overcome, concerns the damage that could be done to specimens in the process of winding, when they may become crushed or broken, rendering identification a longer and more tiring process than the examination of ordinary tow-net samples. The condition of the plankton has now been greatly improved by the introduction of folded edges to the silk covering banding, which take off the pressure from the



TEXT-FIG. 31.—Graphs of total Copepoda on the Bremen line, 1932–1934, arranged so that their midday points lie directly below each other. The broken lines connect the times of sunrise and sunset.

plankton imprisoned between the two layers of gauze. This has already been described in the section dealing with recent improvements to the machine (p. 26).

Another limitation, and one which applies to all tow-nets, is that one cannot sample the whole range of plankton organisms by using one grade of silk—indeed, as is well known, a vast quantity of the nannoplankton will escape through the meshes of the finest gauze made. This matter has already been discussed in the section on " The Catching Power of the Machine " (p. 44).

MECHANICAL FAILURES, AND TREATMENT OF PARTLY FAULTY RECORDS.

From time to time breakdowns in the mechanism have occurred, resulting in a stoppage of the record. The following have been the principal causes of such breakdowns.

1. The brakes on the supply spools have been adjusted too tightly, so that they jam and the gauze fails to wind off.

2. Pieces of grit may get caught in between one of the rollers and part of the frame, so that the roller no longer turns and prevents the gauze from winding on.

3. The friction-drive may become too slack so that it slips the whole time, with the result that the gauze bandings which have passed through the driving-rollers are not taken up by the storage spool ; they will then curl over the driving-rollers until eventually they may get caught round the forward driving-roller and be wound upon it till the mechanism jams. This cause of breakdown has now been eliminated by the substitution of a fusee for the shipping friction-drive (see p. 24).

4. Another stoppage is one which will only develop in an old machine, and is due to the wearing of the rubber ends of the forward driving-roller against which the toothed metal ends of the rear driving-roller press. The rubber becomes reduced in diameter, so that the other roller no longer exerts sufficient pressure to drive on the gauze ; the blunt teeth just slip on the gauze, which remains stationary. This may be avoided by the careful inspection of machines, and the replacement of the ends of the rollers by new ones as soon as they show signs of wear.

If a recorder runs successfully for part of its journey and then stops through some mechanical defect, it is usually found possible to make use of the successful part of the record in the survey. Such records in the 1932–37 period are marked by a " D " in the remarks column of the list of records which forms ' Bulletin ' No. 2. Records which failed from the very beginning, or for other reasons were quite useless, have been omitted from the list.

A failure, if for no other reason, is at once apparent by only a limited number of sections having been wound on, and it is usually possible to be certain that the mechanism stopped abruptly. The plankton is deposited in a normal manner along the roll until the last section to be exposed, and this is found densely coated with organisms, indicating that at this point it remained stationary in the water-tunnel. Sometimes a gradual increase in the number of organisms on the last few sections to be exposed will suggest a gradual retardation before stoppage, and such will be discarded. The distance covered by the recorder before the stoppage, or the suspected retardation, can be approximately estimated by knowing the number of miles per section which that particular machine had recorded on former successful runs. This part of the record is analysed and graphed for the approximate distance so estimated.

Occasionally another type of defect has developed which does not result in an actual stoppage of the recorder. The silk-catching roll may move over to one side so that one of its edges comes out of the recessed slot at the side and allows an escape of plankton. This may result from a wearing of the rubber ends of the driving roller, as in 4 above, allowing one of the edges to travel inwards, or be caused by the brake on the supply spool having been too slack, so that the silk-catching roll ran off too easily and was pushed out of place by the force of the water pressure in the tunnel. Such rolls from which there may be some loss of plankton (sometimes only a little, but at others more) have a more limited quantitative value (varying according to circumstances) and will always serve a qualitative purpose in indicating the presence of certain organisms in an area at a particular time. They are, fortunately, a rare occurrence. Such records which have less quantitative validity, for this or other reasons, are marked with a *Q* in the list of records in 'Bulletin' No. 2.

ACKNOWLEDGMENTS

The existence and development of the plankton recorder survey of the North Sea has been made possible through the kind help of a great many different people, both individuals and public and private bodies. To all of these we express our deep sense of gratitude.

First of all I must express our keen appreciation of the encouragement and support we have received in the development of these investigations from the former Principal of the College, Dr. A. E. Morgan, his successor Mr. J. H. Nicholson, and the members of the College Council and Senate.

The College provided the laboratories and £1000 capital expenditure on equipment, and have continued to make a substantial annual contribution towards the research expenses. His Majesty's Treasury, on the recommendation of the Development Commissioners, have made an annual grant, which has been maintained at an average of £1076 on the first five and a half years and has been increased to £2583 in the present year. Annual grants have also been received from the Leverhulme Trustees, the Hull Fishing Vessel Owners' Association and the Fishmongers' Company of £250, £100 and £50 respectively. In 1931 the Council of the Royal Society made a grant of £140 towards plankton recorder equipment, and in 1934 Mr. (now Sir Malcolm) Stewart generously provided £100 to cover the cost of replacing a recorder lost at sea.

We are most grateful for the generous co-operation we are receiving from the many steamship lines taking part in the survey. It will be realized that the survey is entirely dependent upon the kind interest taken in it by the directors of the different companies, and the never-failing help so willingly given by the captains, officers and crews of the ships concerned. It is impossible for us adequately to express our gratitude for this great service. The following is a list of the steamship lines co-operating, together with the names of the ships which are working or have worked the recorders:

The Argo Shipping Company:
  S.S. *Albatross*, *Geier*, *Habicht*.
The Associated Humber Lines:
  S.S. *Dewsbury*, *Jervaux Abbey*, *Whitby Abbey*.
Det Bergenske Dampskibsselskab:
  S.S. *Cygnus*.
Messrs. James Currie & Co.:
  S.S. *Courland*, *Hengist*, *Gothland*, *Lapland*, *Zealand*.
Ellerman's Wilson Line:
  S.S. *Dago*, *Salerno*, *Spero*.
Icelandic Shipping Co.:
  S.S. *Godafoss*, *Gullfoss*.
The North of Scotland and Orkney and Shetland Steam Navigation Co.:
  S.S. *St. Sunniva*.
The United Shipping Co.:
  S.S. *Frigga*, *Vidar*.

It is impossible to mention by name all the representatives and officers of the different companies who have rendered us so much assistance, but I would particularly like to acknowledge our debt of gratitude to Mr. F. Broadhurst, of Messrs. Sivewright, Bacon and Company, of Manchester, agents for Det Bergenske Dampskibsselskab, and Mr. A. J. Evans of the United Shipping Company in London, who are doing so much at these two ports to help us in the dispatch of recorders to ships so far from our laboratories.

As already explained, the work is being carried out in close co-operation with the research departments of the Ministry of Agriculture and Fisheries and of the Fishery Board for Scotland. To them, and to the captains and officers of their research ships, the *George Bligh* and the *Explorer*, we are indebted for the facilities kindly given us in making tests with new designs of recorders at sea.

Our thanks are also due to the *Discovery* Committee of the Colonial Office for the kind loan of a plankton recorder when not in use on the R.R.S. *Discovery*, and for permission to reproduce a number of figures in the present paper from the author's description of the plankton recorder in Vol. XI of the '*Discovery* Reports' and for the loan of blocks (Text-figs. 5 to 12, 15 and 18 to 25).

In the detailed description of the original recorder (Hardy, 1936*a*), acknowledgment has been made of the great help received from the staff of H.M.S. *Vernon* in the original design of the paravane planes employed. At the beginning of our present survey we were again indebted to them for kindly carrying out further tests, and improving the stability of the machine for higher speed towing. We are also indebted to the Admiralty for the loan of a depth recorder which has been most useful in experimental work.

Finally, I must record our appreciation of the work of Mr. A. W. Hawkins, the College Superintendent of Works, and his workshop staff. Practically the whole of our equipment is now made in the College workshop. Text-fig. 16, on p. 31, shows a set of recorders and ships' winches in process of construction for the extension to the survey in 1938. It would be difficult to overestimate the advantages of being able to see and discuss the construction of machines at various stages of progress, and to have the facilities for rapid repairs and alterations close at hand. The development of our work owes much to the keen interest, skill and ready co-operation of Mr. Hawkins and his staff.

Extension of the Survey.

As already explained, it was hoped that the first five years' survey in the southern North Sea would be in the nature of a trial of the method, which might be a prelude to a more comprehensive survey which would cover the whole of the North Sea from north to south. In 1937 the Development Commission, after an examination by their Advisory Committee on Fishery Research of the results of this first five years' work, recommended that the grant from His Majesty's Treasury should be increased so that, together with an increase in the College contribution, the funds were provided to bring this project into effect.

The extended survey was planned by the Joint Advisory Board referred to on p. 5, so that it might best fit in with the research programmes of the Ministry of Agriculture and Fisheries, the Fishery Board for Scotland, and the International investigations generally. The following new lines were introduced :

From the Pentland Firth to Bergen on the S.S. *Cygnus* of the Norwegian line Det Bergenske Dampskibsselskab, sailing between Manchester and Norway.

From the Pentland Firth to Hamburg on ships of Messrs. James Currie & Co., sailing from Glasgow.

From Leith to Aberdeen and to Lerwick (during the summer months only), on the S.S. *St. Sunniva* of the North of Scotland and Orkney and Shetland Steam Navigation Co.

From Leith to Hamburg and from Leith to the Skagerrak, also on ships of Messrs. James Currie & Co.

From Hull to Norway on the S.S. *Salerno* of the Ellerman's Wilson Line.

A chart of the full survey is given in Text-fig. 3 on p. 7.

Three new appointments were made to the scientific staff : Messrs. W. Macnae, B.Sc., N. B. Marshall, B.A., and C. B. Rees, B.Sc., being appointed in the autumn of 1937[1]. To operate the new northern lines it was necessary to open a new laboratory at Leith, a sub-station of the University College of Hull Department of Oceanography. Suitable premises were found at 23, Sandport Street, near the docks at Leith. Mr. C. E. Lucas, who has been on the staff at Hull since the beginning of the recorder survey, was appointed in charge of this station.

The extension was approved by His Majesty's Treasury in September of 1937 ; the necessary alterations and the equipment of the new laboratory were completed by the end of the year ; the first two new lines were run in January, and the full programme was in operation by February, 1938. A report on the more important results of the extended 1938 survey will be published immediately after those on the 1932–37 survey, which are now in the press. The proposed programme of future publications will be found on p. iii of cover.

At the beginning of the present year (1939) the recorder and equipment on the S.S. *Salerno*, running between Hull and Norway, were transferred to the S.S. *Gullfoss* of the Iceland Shipping Co., to work a line across the Faero-Shetland Channel on the route from Leith to Reykjavik. When the S.S. *Salerno* was equipped it had been expected that she would run regularly direct to Stavanger ; actually, through alterations in trade conditions, she sailed first to Christiansand, and so followed a course too close to that of S.S. *Spero*, on the Hull to Copenhagen line, to be worth while. The importance of a knowledge of the variations in the North Atlantic current through the Faroe-Shetland Channel for a better understanding of the Atlantic influx into the northern North Sea has long been realized, and it is hoped that this new line will be particularly valuable in providing information regarding its planktonic content which can be linked with the conditions found in the North Sea.

SUMMARY.

An outline is given of the plan and scope of an ecological survey of the plankton of the North Sea begun in 1932, and carried out by using continuous plankton recorders once a month on several regular steamship lines between this country and the Continent. It represents an attempt to apply meteorological-like methods to the investigation of the changing plankton distribution over a wide area with the passage of time. The variations in production in different seasons and different years can be compared and the changes are to be correlated with the changing climatic and hydrological conditions on the one hand and the fluctuations in the fisheries on the other.

The structure and working of the plankton recorder are briefly described, together with some recent improvements in design. This is followed by an account of the methods of working at sea and in the laboratory, and by a discussion of the interpretation and charting of the results, the catching power of the machine, the scale of working, the limitations of the method, the causes of mechanical failures, and the treatment of partly faulty records.

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[1] Since going to press Mr. Macnae has resigned his appointment to take up a teaching career and his place will be taken by Dr. H. G. Stubbings, M.A., Ph.D., B.Sc.

Extensions of the survey to cover the northern part of the North Sea in 1938, and to include a line across the Faroe-Shetland Channel in 1939 are briefly described.

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[*Hull Bulletins of Marine Ecology, Vol. I, No. 2, pp. 59–71, November, 1939.*]

ECOLOGICAL INVESTIGATIONS WITH THE CONTINUOUS PLANKTON RECORDER:

SUMMARY LIST OF RECORDS, 1932-37

INTRODUCTION.

THE following list contains particulars of all the records made with the continuous plankton recorder in the plankton survey of the southern North Sea, from its inauguration in June, 1932, up to the end of 1937. In addition particulars are given of some trial records made in September and October, 1931 (B1 and B2), and in January, 1932 (C1 and C1*a*), before the beginning of the survey proper. The object, plan and methods of the survey have already been discussed in 'Bulletin' No. 1.

The recorders have been used in this period on five different lines: by ships sailing between Hull and Bremen, Hull and Copenhagen, London and Esbjerg, Hull and Iceland, and Hull and Rotterdam. The lines will be referred to in the list by the letters B, C, E, I and R respectively. A chart of the lines of the 1932–37 survey is shown in Fig. 1.

On the B line the recorder was used by the S.S. *Albatross* of the Argo Shipping Company. The machine was usually put down in the vicinity of the Outer Dowsing Light-vessel, and hauled at the Borkum (or latterly at the Norderney) Light-vessel, off the German coast, or was run in the reverse direction. The position of the start of each record and the distance towed are given in the list in the manner explained below.

On the C line the recorder was used by the S.S. *Spero* (or S.S. *Dago* for part of 1936) of Ellerman's Wilson Line. The machine was usually put down in the vicinity of the Humber Light-vessel and towed for 250 miles (or latterly 350 miles) towards the Skagerrak, or in the reverse direction.

The E line, which only began in 1936, is operated by the United Shipping Company (S.S. *Frigga* or S.S. *Vidar*). The record is taken between the Sunk Light-vessel and the Graadyb Light-vessel.

The I line was an experimental line run occasionally during 1933–1935 between the Humber Light-vessel and the Pentland Firth (and on two occasions on sections between the Pentland Firth and Iceland) by the S.S. *Godafoss* of the Iceland

Shipping Company. This route was discontinued, as it was considered desirable at this stage of the survey to concentrate all our machines on the southern section of the North Sea.

The R line has been worked since the beginning of the survey by ships of the Associated Humber Lines: the S.S. *Whitby Abbey*, *Jervaux Abbey*, and *Dewsbury*. The recorder is usually put down in the vicinity of the Dudgeon Light-vessel, and hauled at the Maas Light-vessel against the Dutch coast.

The courses taken by the ships on the different lines are as follows:

B line: Humber L.V.—Outer Dowsing L.V.—Borkum L.V.—Norderney L.V. (L.V. = Light-vessel.)
C line: Humber L.V.—Hanstholm Lighthouse.
E line: Sunk L.V.—Graadyb L.V.
I line: Humber L.V.—Rattray Head—Duncansby Head.
R line: E. Dudgeon L.V.—Newarp L.V.—Maas L.V.

The positions of the above points in terms of latitude and longitude are:

Borkum L.V.	53° 46′ N., 6° 04′ E.
Duncansby Head	58° 39′ N., 3° 01′ W.
E. Dudgeon L.V.	53° 20′ N., 1° 00′ E.
Graadyb L.V.	55° 20′ N., 8° 05′ E.
Hanstholm Light	57° 07′ N., 8° 36′ E.
Humber L.V.	53° 34′ N., 0° 21′ E.
Maas L.V.	52° 01′ N., 3° 54′ E.
Newarp L.V.	52° 47′ N., 1° 53′ E.
Norderney L.V.	53° 56′ N., 7° 14′ E.
Outer Dowsing L.V.	53° 34′ N., 0° 59′ E.
Rattray Head	57° 37′ N., 1° 49′ W.
Sunk L.V.	51° 52′ N., 1° 37′ E.

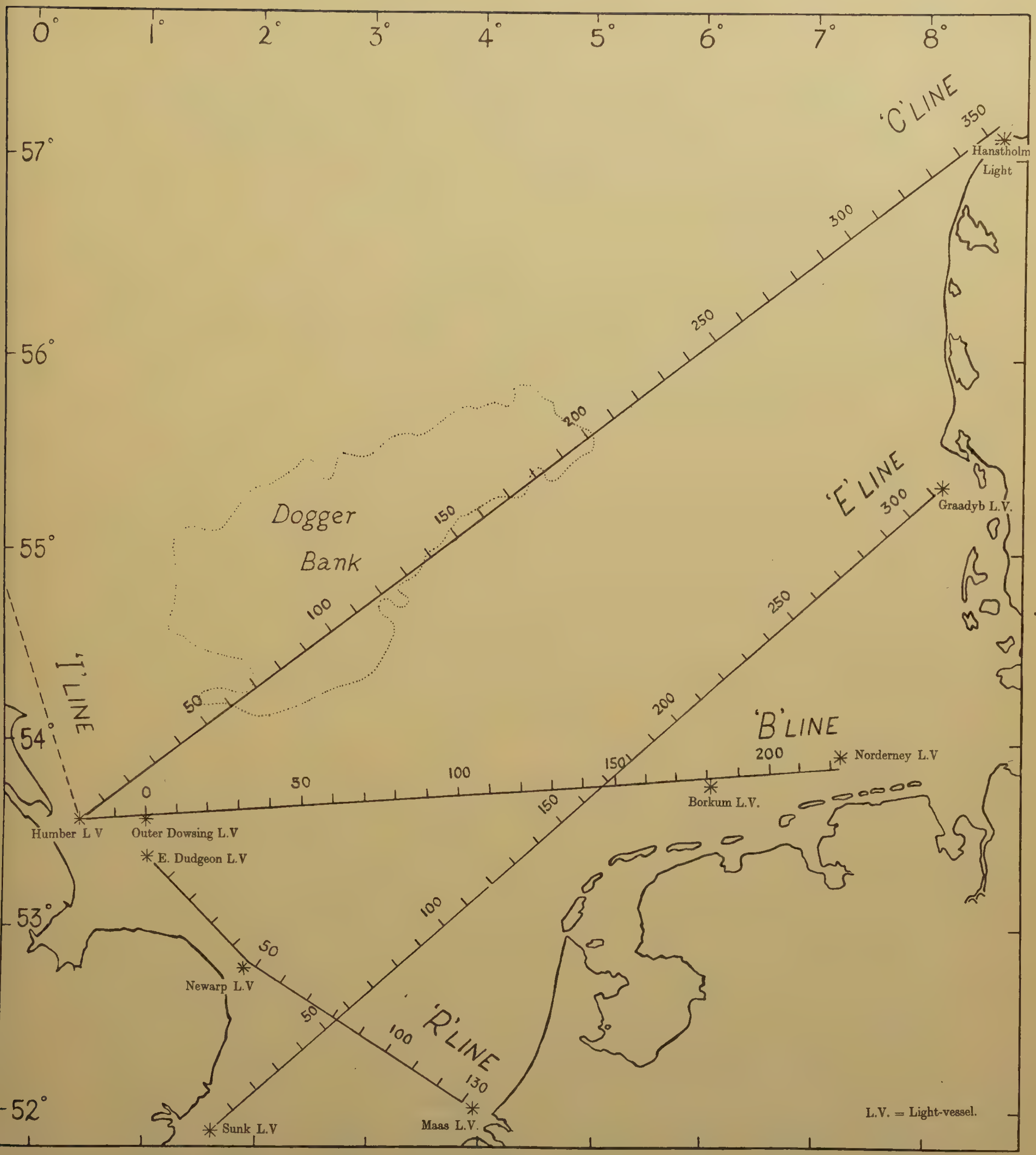
The recorders are towed at a standard depth of 10 metres below the surface on all lines except for a distance of some 30 miles in shallow water on the C line, where it passes over the south-west patch of the Dogger Bank, and is hauled up to 8 metres for safety.

The aperture to the water tunnel was ¾ in. square from the beginning of the survey until May, 1937, when it was reduced to ½ in. square, as the mileage per section ratio was increased to approximately 5 miles per section (see 'Bulletin' No. 1, p. 47).

Explanation of the List of Records.

Route and Number of Record.

The routes B, C, E, I and R defined above are taken in alphabetical order, and the numbers of the records on each route follow chronological sequence. When a record number and its details are omitted it indicates that no useful record was obtained; in some cases the mechanism failed at the very beginning of the run, and in a few others a machine was lost through accident.


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
'C' LINE
350
300
250
200
150
100
50
Hanstholm Light
Dogger Bank
'E' LINE
300
250
200
150
100
50
Graadyb L.V.
'I' LINE
'B' LINE
0
50
100
150
200
Norderney L.V
Borkum L.V.
Humber L V
Outer Dowsing L.V
E. Dudgeon L.V
50
Newarp L.V
'R' LINE
100
130
Sunk L.V
Maas L.V.
L.V. = Light-vessel.

Text-fig. 1.—Chart showing the recorder lines in the 1932–1937 plankton survey of the southern North Sea. The distances along the lines from the usual starting positions (light-vessels) are shown in miles. The course of the " I " line is shown in Text-fig. 2 of 'Bulletin' No. 1.

Date and Time.

The times at which the recorder was streamed (shot) and hauled are given. Against some records two such entries are made ; this indicates that the recorder was hauled and put down again during passage on account of rough weather, fog, or passing over the nets of herring-drifters.

Position of Start.

The position at which the recorder is put down at the start of a record is given in miles along the route from the position of a light-vessel which the ship passes on leaving or approaching the English coast. The light-vessels used for this purpose on the different routes are as follows :

B line : Outer Dowsing L.V. (53° 34′ N., 0° 59′ E.).
C line : Humber L.V. (53° 34′ N., 0° 21′ E.).
E line : Sunk L.V. (51° 52′ N., 1° 37′ E.).
I line : Humber L.V. (see above).
R line : E. Dudgeon L.V. (53° 20′ N., 1° 00′ E.).

If the position is given as 0, this means that the record started exactly at the light-vessel (*e. g.* B10). If it is given as 14 or 9 (*e. g.* B8 and B15), it means that the record started 14 or 9 miles along the route *past* the light-vessel in a direction away from the English coast. If it is given as –23 or –18 (*e. g.* B1 and B9), it means that the record started 23 or 18 miles *from* the light-vessel, but *before reaching it* on passage from the English coast. If the number is given in *italics* as *247* or *182* (*e. g.* B2 and B3), it means that the record started 247 or 182 miles along the route from the light-vessel, but that the recorder was towed *towards* the English coast.

Mileage Recorded.

Here is given the number of miles recorded from the position of the start of the record. This gives the position of the end of the record, which may be marked off along the route of the particular line concerned. The routes are shown in Text-fig. 1, and defined in terms of latitude and longitude in the introduction above. On occasions when there has been a mechanical defect resulting in a stoppage of the mechanism (marked " D " in remarks column), the mileage recorded is estimated from the number of sections on the gauze which have been exposed before the stoppage, by taking a ratio of miles per section based on the past records of the machine concerned. In such cases the estimated mileage is only an approximation and is given as "*ca.* 73" or "*ca.* 153" (*e. g.* B16 and B24). When the recorder has not been towed the whole distance between two light-vessels, the mileage given is that of the ship's automatic log. It is found that for the earlier records this position, due to the effects of sea and tides, may be anything up to 10% in error ; latterly, by obtaining in addition log readings from the ship when it actually passed the light-vessel in question, corrections have been made. A discussion on the possible errors in positions in mid-course through the effects of sea and tide will be found in 'Bulletin' No. 1, p. 39. Mileage figures in *italics* indicate that the recorder was towed *towards* the English coast, otherwise the tow was outwards from the English coast.

Miles per Section.

As explained in 'Bulletin' No. 1, the gauze sampling the plankton is divided into numbered sections by transverse lines 2 in. apart. The "miles per section" represents the mileage travelled by the machine in the time taken for each dividing line on the gauze to wind across the water-tunnel. It is obtained by dividing the mileage recorded by the number of sections of the gauze fully exposed. For a detailed consideration of the significance of this mileage per section, see 'Bulletin' No. 1, p. 36. In the middle of 1937 the ratio was increased to approximately 5 miles per section by altering the setting of the propeller blades, and the aperture to the water-tunnel reduced from $\frac{3}{4}$ in. square to $\frac{1}{2}$ in. square (see 'Bulletin' No. 1, p. 47).

As explained under "Mileage Recorded", when the mechanism has stopped through some defect, the ratio of miles per section is based on past or later records of the machine and is given as "*ca.* 2·1" or "*ca.* 1·7" (*e.g.* B16 and B24). Such ratios must be regarded as only approximate.

Wind, Sea and Weather.

The conditions of wind, sea and weather were recorded by the ships' officers on the log forms provided. The following abbreviations are used in the list :

Wind.

bk.	backing.	md.	moderate.
fh.	fresh.	st.	strong.
gl.	gale.	var.	variable.
lt.	light.		

Sea.

cf.	confused.	r.	rough.
cm.	calm.	sl.	slight.
h.	heavy.	sw.	swell.
md.	moderate.	v.r.	very rough. high.
mdg.	moderating.		

Weather.

bp.	bright periods.	q.	squalls.
c.	cloudy.	r.	rain.
cl.	clear.	s.	snow.
f.	fog.	st.	storm.
h.	hail.	t.	thunder.
m.	mist.	un.	unsettled.
o.	overcast.	z.	haze.
p.	passing showers.		

" Analysed by."

Up to 1936 each record was analysed for all classes of organisms by one, or occasionally two members of staff; the initials stand for their names as follows:

L.	Mr. C. E. Lucas.
H.	Dr. G. T. D. Henderson.
F.	Mr. J. H. Fraser.
R.	Mr. K. M. Rae.

From 1936 a new procedure was adopted: Mr. Lucas specialized on the phytoplankton, Mr. Rae on the Copepoda, and Dr. Henderson on the zooplankton other than Copepoda. Each record was now analysed by all three, and this new method is indicated in the list by the letter " N ". Some of the 1937 records were analysed by the new members of staff appointed to take part in the extended survey of 1938; phytoplankton by Mr. W. Macnae, Copepoda by Mr. C. B. Rees, and zooplankton other than Copepoda by Mr. N. B. Marshall.

Remarks.

The following are the explanations of the reference letters used in the remarks column:

C: The experimental introduction of a banding of cellophane in addition to the plain silk gauze as a covering to the graduated silk gauze. This was discarded after a trial period (see 'Bulletin' No. 1, p. 27).

D: A mechanical defect resulting in a stoppage of the mechanism. The distance travelled before the stoppage occurred is estimated from the number of sections of silk wound on before the stoppage, by estimating the ratio of miles per section from the previous records of the machine. In these cases the ratio and mileage recorded are only approximations.

d: A slight mechanical defect, such as a crumpling of the silk, which, however, does not appreciably affect the ratio of miles per section.

E: The introduction of folded edges to the silk banding, either graduated or plain, to improve the condition of the plankton collected by reducing the pressure on it when wound on to the storage spool (see 'Bulletin' No. 1, p. 26).

F: The introduction of the fusee mechanism in place of the slipping clutch for driving the storage roller (see 'Bulletin' No. 1, p. 24).

H: Indicates that the recorder was hauled up before the completion of the normal distance on account of bad weather, fog or passing over the nets of herring-drifters; it may also indicate that the streaming of the recorder was delayed for the same reasons. Often, when conditions improved or the drifters were past, it was put down again to complete the remainder of the distance, as will be shown in the list by a second entry of figures. The same symbol H is also used to indicate the machine was hauled up for observation when one of our staff accompanied the ship to inspect its working.

P : indicates that the record was analysed for phytoplankton only. At the time of the autumn East Anglian herring fishery a number of extra records have been taken from 1934 onwards to give a more detailed knowledge of the changes in the phytoplankton, and these usually have been analysed for phytoplankton only.

Q : Indicates that the record may have mainly qualitative value, due to some defect that *may* have resulted in a loss of plankton. If such a record has been used quantitatively, then its suspected limitations are stated in the report concerned.

R : A possible retardation of the mechanism suggested by a high miles per section ratio and an abnormal accumulation of all forms of plankton on certain (discarded) sections.

V : Indicates that the silk had over-wound due to an unexpectedly long tow. As in D, only an approximate ratio can be used.

Route and number of record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—	Remarks.
		Shot.	Hauled.								
	1931.										
B 1	15/16.ix	2320	0615	— 23	*ca.* 90*	*ca.* 0·97*					
		1322	2222	144	102	0·97	—	—	—	F.	H
2	17/18.x	1924	1630	*247*	*238½*	1·23	—	—	—	F.	
	1932.										
3	8.vi	0535	2400	*182*	*195*	1·70	—	—	—	L.	
4	20.vii	0420	2310	*182*	*200*	1·52	—	—	—	L., F.	
5	17.viii	0445	2227	*182*	*187*	1·33	—	—	—	F.	
6	28.ix	0520	2300	*182*	*186*	1·68	N.W., md.	sl.	fair	L.	
7	26.x	0620	1920	*182*	*125*	1·49	W., st.	r.	o. r.	L.	
8	5.xi	0420	2005	14	168	1·62	N., md.	md.	fair	L.	
9	18/19.xi	2350	1755	— 18	200	1·61	W., lt.	cm.	c.f.	L., F.	
10	10.xii	0000	1810	0	188	1·58	W., md.	md.	"	L.	
	1933.										
11	25.i	0010	2010	0	186	1·63	"	"	cl.	L.	
12	19.ii	0000	1300	*182*	*136*	1·53	"	"	s.	L.	H
13	15.iii	0000	1700	— 22	190	1·62	S.W., fh.	"	z.	L.	
1[illegible]	10.v	0000	1540	9	176	1·73	"	"	r.	F.	
16	31.v	0405	1910	21	*ca.* 73	*ca.* 2·1	N.E., lt.	cm.	fair	F.	D
17	16.vii	0000	1820	*187*	*183*	1·63	W., lt.	"	"	F.	
18	22/23.viii	2310	1610	— 1	187	1·73	"	sl.	r.	F.	
19	19/20.ix	2320	1800	— 5	178	2·0	S.W., md.	md.	fair	F.	
20	27.ix	0250	2030	0	180	2·07	N.E., md.	"	r.m.	H., F.	
21	31.x/1.xi	2330	1640	— 1	184	2·10	N.W., fh.	r.	r.q.	F.	
23	22.xi	0040	1730	— 4	168	2·07	E., lt.	cm.	z.	L., F.	
24	17.xii	0400	2330	*201*	*ca. 153*	*ca.* 1·7	S.W., lt.	sl.	fair	F.	D
	1934.										
25	20/21.i	1800	0800	0	156	1·79	S., lt.	md.	"	F.	
26	24/25.ii	1615	0805	4	*ca.* 165	*ca.* 2·5	S.W., md.	"	z.	F.	D
28	24/25.iii	1757	1045	1	181	2·08	N.W., md.	"	fair	F.	
29	27/28.iv	2010	1615	— 23	*ca.* 72	*ca.* 2·0	E., lt.	cm.	p.	H.	
31	19.v	0050	1856	— 10	190	2·64	S., lt.	md.	fair	L.	R
32	16.vi	0000	0900	— 10	94	2·24	S.E., lt.	cm.	fair	F.	H
33	20/21.vi	0900	0805	*182*	*193*	2·61	W.–N.W., st.	v.r.	c. cl. r.	L., F.	
34	27/28.vii	2200	1750	— 22	204	2·40	W., st.	r.	r.	F.	d
35	24/25.viii	2200	1700	— 9	193	2·05	N.E., lt.	md.	"	L.	
36	7/8.ix	2240	1704	0	188	2·07	Ely., lt.	cm.	fair	L.	
37	29.ix	0200	1946	0	*ca.* 110	*ca.* 1·25	S.S.E., md.	md.	"	F.	V
38	6.x	0410	1610	68	139	1·25	W., md.	"	"	F.	P, Q
39	13.x	0405	1810	36	145	1·67	N.W., md.	"	"	F.	
40	19/20.x	2235	1435	0	*ca.* 185	*ca.* 1·2	W.S.W., fh.	"	r.	F.	P, Q
41	27.x	0405	1210	36	81	1·35	S.W., gl.	v.r.	st.	L.	H
42	2/3.xi	2245	1520	0	*ca.* 84	*ca.* 1·4	W., lt.	md.	fair	L.	D, P
43	10.xi	0000	1800	— 4	166	1·61	S.E., fh.	"	o. c. r.	F.	
44	17/18.xi	0800	0140	14	173	1·50	E., md.	"	c. cl.	F.	P
45	24.xi	0045	1720	9	167	1·62	E., lt.	cm.	fair	L., F.	P
46	1.xii	0500	2115	0	169	1·58	S.W., md.	md.	un.	F.	
	1935.										
48	15/16.i	2245	0610	5	85	1·49	N., lt.	cm.	f.	F.	H
49	29/30.i	1800	1200	0	186	1·41	N., md.	md.	r.	F.	
50	13.ii	0800	2400	21	170	1·56	S.W., md.–fh.	"	"	L.	
51	23.iii	0000	1710	0	185	1·53	W.S.W., st.	md.–r.	"	F.	
52	30.iv/1.v	2200	1640	0	185	1·52	E., md.	md.	fair	H.	
53	28/29.v	2145	1640	0	185	1·76	N.E., md.	"	"	L.	

* See explanation on p. 62 regarding use of abbreviation "*ca.*".

Route and number of record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—	Remarks.
		Shot.	Hauled.								
	1935.										
B 54	26.vi	0815	2400	14	171	1·86	Sly., md.	md.	r.m.	R.	
55	16/17.vii	2300	1555	0	174	1·58	S.E., lt.	cm.	fair	H.	
56	13/14.viii	2025	1600	– 20	*ca.* 168	*ca.* 1·5	N.W., lt.	md.	,,	H., L.	D
58	10/11.ix	2215	1535	0	182	1·49	S., lt.	sl.	,,	L.	P
59	25/26.ix	2230	1700	0	182	1·58	N.W., fh.	h. sw.	c.	L.	P
60	2.x	0800	2330	67	173	1·53	Wly., lt.	md.	fair	L.	P
61	8/9.x	2237	1455	0	186	1·68	S.W., st.	v.r.	,,	L.	
62	16.x	0000	1645	– 5	186	1·62	S.W., md.	md.	r.	L.	P
63	23/24.x	2300	1850	0	183	1·74	S.E., st.	md.–r.	c.	L., R.	P
64	31.x	0010	1706	– 4	186	1·69	S.W., st.	,,	c. r.	L.	P
65	6.xi	0545	2200	3	*ca.* 48	*ca.* 2·0	S.W., md.	md.	r. m.	R.	D
66	13.xi	0010	1840	0	*ca.* 70	*ca.* 1·5	S., st.	r.	—	L., H.	D
67	27.xi	0010	1545	2	173	1·53	W., st.	,,	—	L.	
68	15.xii	0000	1800	*189*	*182*	1·58	S.W., fh.	,,	r.	L.	
	1936.										
69	4.i	0525	2205	0	181	1·65	W., md.	md.	fair	L.	
70	7/8.ii	2324	1730	0	181	1·51	S.E., md.	,,	,,	L.	
71	29.ii	0410	0010	4	185	1·595	N.E., fh.	h.–sw.	q. r. s.	N.	
72	17/18.iv	2300	1800	0	154	1·75	N.W., gl.	v.r.	s. r.	N.	d
73	22.v	0010	1630	0	184	1·63	N.E., lt.	sl.	c.	N.	Q
74	20/21.vi	2308	1700	– 4	*ca.* 147	*ca.* 1·75	E., md.	,,	cl.	N.	D
75	26.vii	0400	1915	15	*ca.* 148	*ca.* 1·75	S.W., md.	md.	c.	N.	D
76	29/30.viii	2042	1230	0	189	1·67	W.N.W., md.	,,	z.	N.	
77	12/13.ix	2035	1330	0	187	1·51	S.E., md.	,,	cl.	N.	P
78	26/27.ix	1840	1050	0	184	1·53	N.W., md. lt.	,,	c. r.	N.	
79	3/4.x	2300	1530	0	184	1·51	W., md.	,,	,,	N.	P
80	11.x	0010	1620	60	*ca.* 35	*ca.* 1·5	N.E., lt.	,,	,,	N.	D, P
81	18.x	0005	1600	0	*ca.* 38	*ca.* 1·5	N.W., gl.	v.r.	—	N.	D, P
82	24/25.x	1745	0950	0	182	1·86	S., st.	r.	—	N.	
83	31.x/1.xi	2350	1600	0	182	1·625	N., md.	md.	c.	N.	P
84	7/8.xi	1840	1100	– 8	176	1·81	S., fh.	v.r.	,,	N.	P
85	14/15.xi	2035	1235	– 23	183	1·55	W.N.W., fh.	md.	,,	N.	P
86	25/26.xi	1920	1115	– 5	179	1·74	E.N.E., md.	,,	,,	N.	
87	1/2.xii	2300	1600	– 16	*ca.* 50	*ca.* 1·75	N.W., st.	r.	c. r. q.	N.	D
88	16/17.xii	1200	0350	– 12	183	1·62	W., fh.	md.–r.	c.	N.	
	1937.										
89	23/24.i	1850	1410	– 5	*ca.* 105	*ca.* 1·75	S., gl.	v.r.	—	N.	D
91	16/17.ii	2350	1600	– 23	185	1·38	S., lt.	md.	c. r.	N.	
93	23/24.iii	2100	1300	– 23	173	1·41	N.W., lt.	,,	fair	N.	
94	24/25.iv	2015	1435	– 23	*ca.* 149	*ca.* 1·0	N., st.	md.–r.	c.	N.	V
95	15/16.v	1600	1010	– 10	183	4·01	N., lt.	md.	—	N.	
97	19/20.vi	1735	0930	– 21	184	6·30	var. lt.	sl.	—	N.	F
98	11.vii	0005	1600	– 4	*ca.* 175	*ca.* 5·0	N.W.	md.	c. r.	N.	d, C, E
99	7/8.viii	2130	1330	– 21	182	5·35	N., lt.	,,	fair	N.	C, E
100	21/22.viii	2025	1310	– 20	*ca.* 170	*ca.* 5·0	N., lt.–md.	,,	,,	N.	d, C, E
101	4/5.ix	2020	1220	– 20	182	5·58	S., md.	,,	,,	N.	C, E
102	16/17.ix	0700	0025	*175*	*195*	4·49	S.W., md.	,,	o.–bp.	N.	C, E
103	18/19.ix	1930	1835	– 21	227	5·16	N., lt.	sl.	fair	N.	C, E
105	2/3.x	2120	1740	– 4	219	4·76	E., lt.	,,	o.	N.	C, E, Q
106	10.x	0400	2140	24	201	5·43	N., md.–fh.	r.	,,	N.	C, E
107	16/17.x	2000	1650	0	224	5·30	N.W., md.	md.	c.	N.	C, E
108	28.x	0240	2305	*224*	*224*	4·64	S., md.	,,	fair	N.	C, E
109	30/31.x	1800	1600	– 21	241	5·53	S.–S.E., md.	,,	,,	N.	C, E
110	7.xi	0020	1940	0	*ca.* 110	*ca.* 5·0	E., md.–lt.	md.–sl.	op.	N.	C, E, Q

Route and number of record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—	Remarks.
		Shot.	Hauled.								
	1937.										
B 111	13/14.xi	1610	1510	— 23	247	5·74	N.–N.W., fh.–st.	v.r.	q. r.	N.	C, E
112	20/21.xi	2150	2000	— 16	240	5·17	W., md.	md.	fair	N.	C, E
113	28/29.xi	0610	0315	0	233	4·57	N., lt. md.	,,	fair, p.	N.	C
	1932.										
C 1	16/17.i	0130	1930	5	*ca.* 91						
		2000	0630	228	*ca.* 65	*ca.* 1·15	S., md.	S., md.	o.	F.	H, D
1*a*	22/23.i	1830	2110	*348*	*30*						
		2300	0800	*293*	*95*						
		1105	1615	*168*	*58*	1·14	lt. var.	cm.	f.	F.	H
2	11.vi	0105	0450	*255*	*ca. 45*						
		0520	2230	*206*	*ca. 98*	*ca.* 1·7	S., lt.	sl.	—	F.	H, D
3	22/23.vii	2230	0530	*253*	*82*						
		0630	1955	*159*	*ca. 150*	*ca.* 1·55	lt. var.	sl.	—	F.	H, V
4	20.viii	0005	1754	*259*	*ca. 195*	*ca.* 1·3	S.E., lt.	S.E., md.	f.	F.	V
5	30.ix/2.x	2300	0045	*253*	*231*	1·54	S.W.–S.E., st.	r.	—	F.	V
6	11/12.xi	2335	2220	*252*	*247*	1·55	S.E., md.–st.	,,	—	F.	
7	9/10.xii	2210	1920	*250*	*250*	1·52	N.,md.–N.E.,st.	sl.–r.	fair	F.	
	1933.										
8	20/21.i	2200	2035	*260*	*260*	1·61	S.W., lt.	S.W., sl.	,,	F.	
9	18.ii	0010	2232	*250*	*250*	1·58	N., md.	r.–md.	—	F.	
10	18/19.iii	0420	0330	*242*	*241*	1·46	S.S.W.–N., md.	md.–sl.	o.–c. cl.	F.	
12	23/24.vi	2155	1808	*255*	*163*	1·73	E., lt.	N.E., sl.	c.–cl.	H.	D
13	7/8.vii	2255	2030	*250*	*250*	1·61	S.–S.W., lt.	S.W., sl.	fair	F.	
14	16/17.ix	0215	1945	*250*	*187*						
		2115	0134	*47*	*47*	1·81	W., lt.	sl.	c.–cl.	F.	H
15	14/15.x	0410	0250	*252*	*216*	2·04	S.W., st.–lt.	r.–sl.	c., cl.–f.	F.	H
16	11/12.xi	0323	0100	*247*	*247*	1·72	lt.–md.	sl.–md.	o.–c.–cl.	H.	
17	9/10.xii	0300	0100	*248*	*248*	2·03	S., lt.–md.	,,	c. cl.	F.	
	1934.										
18	20/21.i	1930	0850	*137*	*137*	1·93	W.S.W., md.	cf., md.	c. cl. z.	H.	H
19	17.ii	0230	2200	*242*	*214*	1·65	N.W.–W., lt.	W., sl.	o.–cl.–z.	L.	
20	17/18.iii	0410	0600	*249*	*ca. 120*	*ca.* 2·0	S., md.–fh.	S.W., md.	o.–c.	F.	D
21	14/15.iv	0315	0340	*243*	*ca. 63*	*ca.* 1·8	S.E.–S., md.	r.–sl.	o.–cl.	F.	D
22	28.iv	2320	1930	*242*	*242*	2·07	lt., var.	sl.	o.	L.	
23	23/24.vi	0030	2310	*243*	*243*	2·64	N.W., st.–lt.	r.–md.	c.	L.	R
24	21.vii	2300	2130	*253*	*ca. 50*	*ca.* 2·0	S.W.–E.–N.W.	sl.–md.	cl. c.	F.	D
25	18/19.viii	0400	0200	*248*	*241*	2·25	N.W.–S., md.	N.W., md.	o.–cl.–c.	L.	d
26	15.ix	2305	1930	*240*	*ca. 120*	*ca.* 2·0	S.E., lt.–md.	md.	cl. z.	R.	D
27	29.ix	0115	2030	*251*	*ca. 202*	*ca.* 2·0	S.W., md.	,,	o. c.	L.	D
28	27.x	0500	1510	*253*	*64*	1·83	W.S.W., gl.	W.S.W., r.	o. r. h.	H.	H
29	10.xi	0000	2235	*244*	*244*	1·66	S.S.E., md.	md.	o. r. q.	L.	
30	7/8.xii	2300	2300	*251*	*162**	*ca.* 2·0	S.S.W., md.–fh.	,,	c. cl. r.	R.	D
	1935.										
31	18/19.i	2345	1955	*241*	*241*	1·66	lt. var.	sl.	cl.–c. o.	L.	
32	30/31.iii	0320	0025	*242*	*240*	1·86	W., md.	md.	c. cl.–o.m.	L.	
33	26/27.iv	2235	1915	*248*	*246*	1·78	N.W., lt.-md.	,,	c.–o. m.	H., L.	
34	24/25.v	2055	1700	*247*	*244*	1·74	N., lt.–md.	sl.	cl.	R.	
35	22.vi	0930	1930	*119*	*119*	1·78	S., lt.	,,	fair–m.	R.	H
36	20.vii	2345	2145	*248*	*ca. 228*	*ca.* 2·0	var.	,,	o. c. r.	L.	D
37	17.viii	0030	2020	*237*	*ca. 216*	*ca.* 1·75	S., lt.	,,	c. m.	L.	R

* A defect developed in the middle of this record, but righted itself towards the end. The 162 miles recorded represents 128 miles at the beginning of the record and 34 miles at the end ; in between 84 miles were traversed for which the record is doubtful and so discarded. The position at the end of the record is thus 246 miles from the start.

Route and number of record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—.	Remarks.
		Shot.	Hauled.								
	1935.										
C 38	14/15.ix	0050	0200	*250*	*244*	1·81	S.W., fh.	S.W., md.	c. q. r.	L.	
39	12/13.x	0900	0915	*245*	*ca. 212*	*ca.* 1·75	W.S.W., fh.	W., r.	o. c.	L.	R
40	7/8.xii	0400	0220	*256*	*251*	1·82	W., md.	md.	c. o. p.	L.	
	1936.										
41	3/4.i	2300	2200	*253*	*244*	1·81	,,	sl.–md.	o.p.–cl. c.	N.	
42	1.ii	0045	2315	*253*	*249*	1·60	S., md.–lt.	md.–sl.	o. r. m.	N.	
43	29.ii	0130	1920	*220*	*210*	1·71	N.E., st.	N.E., r.	o. s.	N.	
44	27/28.iii	2235	0745	*243*	*ca. 46*	*ca.* 2·0	S.E., md.	md.	o. r. f.	R.	H, D
45	25.iv	0000	2300	*254*	*ca. 74*	*ca.* 2·0	S.S.W., md.	,,	o. r.	N.	D
47	22/23.v	2130	1840	*250*	*ca. 80*	*ca.* 2·0	N.E., md.	,,	o. c.	H., L.	D
48	4.vii	0030	2230	*257*	*ca. 175*	*ca.* 1·75	S.W., md.	sl.	c.	N.	D
49	1/2.viii	0400	0335	*258*	*244*	1·66	var. lt.	,,	,,	N.	
50	28/29.viii	2325	2100	*258*	*243*	1·90	W., lt.	,,	cl. c.	N.	
51	26.ix	0110	2235	*247*	*241*	1·79	N., md.	N., md.	c. r.	N.	
52	7.xi	0030	2345	*256½*	*196½*	1·45	S., st.	md.	c. cl. q. r.	N.	
53	19.xii	1830	2400	*179*	*41*	1·46	S.W., st.	S.W., r.	o. r.	N.	H
	1937.										
54	2.i	0155	1130	*255*	*81*	1·62	W., st.	W., r.	,,	N.	H
55	13.ii	0050	2015	*239½*	*221*	1·53	S.S.E., md.	md.	o. p.	N.	
56	13.iii	0000	2130	*253*	*232*	1·53	S., md.	,,	,,	N.	
57	10.iv	0050	1900	*228*	*208*	1·70	S.S.E., md.	S.S.E., md.	o. c. f.	N.	
58	7/8.v	1920	1620	*253*	*248*	1·66	N., md.–lt.	N., md.–sl.	c. o.	N.	
59	19.vi	0025	2315	*253*	*245*	5·94	var. lt.	sl.	cl. c.	N.	E
60	16/17.vii	0025	2315	*353*	*348*	5·27	S., lt. md.	,,	c. p.	N.	
61	13/14.viii	1342	0200	*353*	*ca. 150*						
		0315	1420	*191*	*ca. 100*	*ca.* 5·5	lt. var.	,,	cl.–o. f.	N.	C, E, H
62	24/26.ix	1630	0215	*353*	*351*	5·04	W., md.	md.	o., cl. c.	N.	C, E
63	16/17.x	0625	1145	21	332	5·07	W., md.–fr.	md.–r.	—	N.	C, E
64	13/14.xi	0410	1322	19	334	5·14	N.–N.E., st.	r., h. sw.	q. cl.	N.	C, E
65	11/12.xii	0230	0845	20½	307	5·22	S.E.–E.S.E., st.	r., h. sw.	—	N.	E
	1936.										
E 1	7/8.i	1850	1954	0	240	1·57	S., lt.–md.	cm.	c.	N.	
2	19/20.ii	0145	0200	0	250	1·52	,,	md.	o. m.–f.	N.	
3	17/18.iii	0110	0400	0	*ca.* 60	*ca.* 1·75	W., lt.	sl.	m.–f.	L.	D
4	13/14.x	0400	0440	0	248	1·80	N.N.W., md.	md.	p.	N.	
5	25.xi	0800	2400	55	180	1·59	N.E., lt.	sl.	c.	N.	
	1937.										
7	9.iii	0530	2320	35	*ca.* 89	*ca.* 1·75	N.E., fh.-st.	r.	o. s.	N.	D
8	14/15.iv	0115	0245	25	*ca.* 204	*ca.* 1·36	E.N.E., md.	md.	o. z. r.	N.	V
9	11/12.v	0739	0445	22	247	4·18	N.E., md.	md.–sl.	c.–o. r.	N.	
10	10/11.vi	1020	0245	50	*ca.* 169	*ca.* 6·0	N.N.E., lt.	sl.	cl.–z.	N.	D, C, E
12	28/29.vii	2209	2226	11	310	5·30	N., lt.–md.	md.	o. q.	N.	C, E
13	24/25.viii	2130	2250	5	290	4·85	lt. var.	cm.	c. o.	N.	C, E
14	21/22.ix	2030	2210	3	298	5·05	var. lt.–md.	sl.	c.	N.	C, E
15	21.x	0040	1942	61	*ca.* 181	*ca.* 5·25	S.S.W., lt.	md.	c. z.	N.	D, C, E, H
16	24/25.xi	0515	0115	82	210	5·47	N.E., lt.	sl.	fair	N.	C, E, H
17	22.xii	0500	1815	69½	139	5·26	N.E.	md.	m.–f.	N.	d, F, H
	1933.										
I 1	24/25.v	1255	2030	77	85	1·63					
		0510	1130	248	72	1·67	N., lt.	cm.	cl.–f.	L.	H
1*a**	25/26.v	1430	1700	58° 54′ N. 3° 55′ W.	240	1·58	,,	sl.	fair	N.	D
2*a**	8/9.vi	1045	1045	63° 20′ N. 19° 43′ W.	*232*	1·59	S.S.W., md.-lt.	md.	c. cl.	. .	D

* Records made in the Atlantic between Pentland Firth and Iceland.

Route and number of record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—	Remarks.
		Shot.	Hauled.								
	1933.										
I 2	10/11.vi	0930	0845	*322*	*288*	1·59	var. lt.	sl.	c. cl.	F.	
3	5/6.viii	1930	1900	*308*	*ca. 160*	*ca.* 2·0	S., lt.	,,	—	L.	D
	1934.										
4	20/21.ii	2220	2210	*329*	*295*	1·98	W., md.	,,	—	N.	
5	2/3.vi	1515	1810	*325*	*314*	1·96	—	cm.	—	N.	
6	28/29.vii	1135	1130	*323*	*ca. 80*	*ca.* 2·0	W., md.	sl.	—	R.	D
7	25/26.viii	1945	1850	*314*	*ca. 36*	*ca.* 2·0	S.W., lt.	cm.	—	R.	D
	1935.										
8	18.iii	?	?	*336*	*299*	1·83	—	,,	z.	N.	
9	15/16.vi	1850	1900	*324*	*290*	1·96	—	—	c. cl.	N.	
	1932.										
R 1	12.vi	0420	0827	79	55	1·38	S., lt.	cm.	—	F.	
2	22/23.x	2100	0015	*133*	*40*						
		0330	0715	*52*	*46*	1·54	W., md.	md.	cl.	F.	H
3	3/4.xii	2015	0530	*133*	*106*	1·68	W., fh.	r.	fair	F.	
	1933.										
4	12.i	0300	1027	45	90	1·61	N.E., st.	,,	cl. c.	F.	
5	23.iii	0206	1000	45	*ca.* 76	*ca.* 2·0	S.E., fh.	md.	fair	F.	D
6	1/2.iv	2050	0658	*133*	*119*	1·57	N.W., fh.	,,	o. c.	F.	
7	7/8.vi	2255	0645	0	103	2·19	E., lt.	cm.	cl.–f.	F.	
8	29/30.vii	2250	0650	*117*	*109*	1·95	N.W., md.	md.	t. q.	F.	
9	30/31.viii	2315	0800	4	114	1·75	E., lt.	cm.	fair	F.	
10	20/21.ix	2315	0930	0	*ca.* 64	*ca.* 2·0	E., lt.–fh.	sl.–r.	o. r.	F.	D
11	21/22.x	2000	0400	*133*	*97*	2·16	S.W., md.	h. sw.	o.	F.	
12	11/12.xi	2035	0515	*133*	*106*	2·21	N., lt.–fh.	md.	c. cl.	F.	
13	6/7.xii	2355	1145	0	133	1·68	E., md.–gl.	r.	fair	F.	
	1934.										
14	11.i	0000	0845	0	100	1·72	S.W., gl.	v. r.	o.	F.	
15	21/22.iii	2304	0800	0	114	1·75	S.W., md.	sl.	cl.	F.	
16	18/19.iv	2300	0900	0	*ca.* 122	*ca.* 2·1	S.W., st.	r.	o. r.	F.	R
17	6/7.vi	2241	0900	0	*ca.* 70	*ca.* 2·0	N., lt.	sl.	—	F.	Q
18	4/5.vii	2225	0745	0	*ca.* 96	*ca.* 2·4	S.E., lt.	cm.	fair	F.	D
19	1/2.viii	2257	0800	0	115	2·05	S.	sl.	cl.–o. r.	F.	
20	29/30.viii	2250	0800	0	*ca.* 113	*ca.* 1·35	S.W., fh.	md.	o. p.	F.	V
21	19/20.ix	2225	0800	0	121	1·59	S.S.W., fh.	r.	o. r.	F.	
22	6/7.x	2130	0800	*133*	*ca. 109*	*ca.* 1·4	,,	,,	o. c.	F.	V
23	10/11.x	2305	0945	0	135	1·29	W., md.	md.	cl.–o.	F.	
24	17/18.x	2306	0310	0	50						
		0535	0920	81	43	1·24	S.W., lt. var.	h. sw.	o.	F.	H
25	3/4.xi	1935	2305	*133*	*42*						
		0010	0600	*77*	*72*	1·44	S.E., st.	r.	fair	F.	d, H
26	14/15.xi	2340	0445	0	63						
		0550	0935	74	41	1·49	E.–S.E.	sl.	o. r.	F.	H
27	1/2.xii	1950	0500	*133*	*114*	1·31	S.S.W., fh.	r.	,,	F.	
	1935.										
28	12/13.i	2050	0530	*133*	*93*	1·63	N.W., st.	v. r.	r. h.	F.	
29	20/21.iii	2303	0830	0	119	3·05	—	cm.	c.	F.	d
30	24/25.iv	2310	0800	0	113	1·79	N.N.E.	md.–r.	o. r.	L.	
31	5/6.vi	2315	0800	0	111	1·48	var. lt.	cm.	o.	L.	d
32	3/4.vii	2301	0745	0	114	1·73	S.W., md.	md.	c. cl.	H.	d
33	31.vii/1.viii	2300	0800	0	124	1·55	E., lt.	sl.	c.	L.	
34	21/22.viii	2256	0800	0	113	1·64	S.E., lt.	cm.	fair	L.	
35	11/12.ix	2200	0700	0	120	1·60	,,	,,	c. cl.	L.	

oute and number f record.	Date.	Time (G.M.T.).		Position of start (see explanation).	Mileage recorded.	Miles per section.	Wind.	Sea.	Weather.	Analysed by—	Remarks.
		Shot.	Hauled.								
	1935.										
36	25/26.ix	2145	0700	0	122	1·54	N., st.	r.	fair	H.	d, P
37	12/13.x	2000	0500	*133*	*113*	1·59	W., lt.	sl.	,,	H.	
38	26/27.x	1930	0030	*133*	*60*						
		0130	0500	*60*	*43*	1·58	W.	r., mdg.	o. r.	H.	P
40	13/14.xi	1955	0020	*133*	*53*						
		0235	0610	*53*	*43*	1·48	S.–S.W., st.	r.	c. r.	R.	
41	23/24.xi	2255	0415	0	66						
		0510	0800	78	35	1·40	N.E., md.	md.	fair, p.	L.	
42	11/12.xii	1937	0442	*133*	*112*	1·53	E., st.	r.	cl.	R.	
	1936.										
43	4/5.i	2245	0750	0	*ca.* 39	*ca.* 1·5	S.W., lt.	sl.	fair, z.	R.	D
46	1/2.ii	2305	0815	3	123	1·54	S.E., lt.	cm.	c.	R.	
47	7/8.iii	2307	0740	0	102	1·76	S.E., md.	md.	fair,	R.	
48	15.iii	0240	0525	46	39						
		0615	0900	96	37	1·63	S.W., lt.	cm.	o.	H.	‡
49	28/29.iii	2325	0200	2	32½						
		0345	0945	56	76	1·49	S.S.E.	,,	,,	L.	
50	22/23.iv	2310	0800	2	*ca.* 98	*ca.* 1·75	N.N.W., fh.	r.	fair	N.	D
51	20/21.v	2255	0800	0	*ca.* 92	*ca.* 1·75	N.	v. r.	o.	N.	R
52	25.vi	0005	0805	11	108	1·69	S., lt.	cm.	—	N.	
53	22/23.vii	2325	0800	1	110	1·55	S.W., md.	sl.–md.	o.	N.	
54	26/27.viii	2305	0800	0	116	1·53	S.E., lt.	sl.	fair	N.	
55	23/24.ix	2315	0800	0	114½	1·59	,,	sl.	fair, z.	N.	
56	7/8.x	2348	0800	0	109	1·58	E., md.	md.	cl. p.	N.	P
57	28/29.x	2257	0400	0	62						
		0600	0940	87	43	1·48	N.W., fh.	r.	cl.	N.	
58	5/6.xii	2310	0800	0	118½	1·65	W., gl.	r.	cl.	N.	
	1937.										
59	20/21.ii	2241	0854	0	121½	1·48*	N.W., st.	v. r.	fair	N.	
61	24/25.iii	2325	0800	0	106	1·51	,,	r.	c. cl.	N.	
62	21/22.iv	2254	0800	0	*ca.* 64½	*ca.* 0·75	S.W.	md.	o. c. p.	N.	V
63	19/20.v	2307	0040	4	21						
		0800	1112	93·5	39½	4·25	S., md.	md.–cm.	f.	N.	F, H
64	27.v	0132	0935	30	*ca.* 60	*ca.* 6·0	W., lt.	cm.	fair	N.	D, C, E
65	16/17.vi	2315	0745	0	113	6·47	N.	md.	,,	N.	C, E
66	14/15.vii	2315	0922	0	98	5·57	S., lt.	cm.	,,	N.	C, E
67	14/15.viii	2200	0230	*133*	*59*	4·72	W.	md.	cl. f.	N.	C, E. H
68	26.viii	0140	0935	28	99	5·05	E., lt.–md.	cm.	o.	N.	F
69	9.ix	0125	0915	29	96	4·57	N.W., md.	md.	cl.–o. c.	N.	F. P
70	23.ix	0200	0945	34	97	4·85	S.E., lt.	cm.	fair	N.	F
72	6/7.x	2335	1145	–1·5	134½	4·64	E., md.	r.–md.	o. c.	N.	C, E
73	13/14.x	2312	0915	0	131	4·94	W.	md.–r.	o.	N.	F, P
74	20/21.x	2323	0200	0	33						
		0800	1215	80	50	4·68	S.	sl.	o. f.	N.	F
75	30/31.x	2000	0020	*133*	*54*						
		0130	0638	*65*	*65*	1·34	S.W., md.	md.	fair	N.	d§
76	6/7.xi	2307	0400	–2·5	*ca.* 57½						
		0540	1025	77·5	*ca.* 47½	*ca.* 0·75	S.E., lt.	md.–cm.	cl.–o. h.	N.	P. V§
77	13/14.xi	2300	0410	–1	66						
		0530	0915	83	48	5·56	N.–N.E.	r.–md.	cl. p.	N.	C, E†
78	29/30.xii	1945	0608	*133*	*133*	4·72	N.E.	md.	o. c. cl.	N.	E

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* In error the silk was cut and worked up at a ratio of 1·62 miles per section.

† A trial made using artificial silk gauze.

‡ 1¼ in. aperture and 40 mesh silk.

§ ¾ in. aperture, records used to check mileage ratio.

[*Hull Bulletins of Marine Ecology, Vol. I, No. 3, pp. 73–170, Plates I–LXIV, March, 1940.*]

ECOLOGICAL INVESTIGATIONS WITH THE CONTINUOUS PLANKTON RECORDER:

THE PHYTOPLANKTON IN THE SOUTHERN NORTH SEA, 1932–37

BY

C. E. LUCAS, B.Sc.

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Introduction: Material and Methods of Investigation.

For reasons given in ‘Bulletin’ No. 1 it was necessary to postpone the publication of this report, which was originally intended to describe the observations for 1932–35 only. Owing to the delay it became possible to include also the records for 1936–37, thus combining the whole of the data for the period when the survey was confined to the Southern North Sea, and forming a basis for the consideration of the more extended survey which began in 1938.

The material for 1932–35 consists of 60 continuous records of the phytoplankton at 10-metres' depth on the Bremen Line (between the Outer Dowsing Light-vessel and the Borkum Light-vessel), 38 on the Copenhagen Line (from the Humber Light-vessel for 250 miles towards the Hanstholm Light), and 41 on the Rotterdam Line (between the Dudgeon and the Maas Light-vessels). They were obtained between June, 1932, and December, 1935 (for further details, see List of Records, 'Bulletin' No. 2).[1] In addition there are also nine scattered records on a line from the Humber Light-vessel to the Pentland Firth, to which brief reference may be made, although they will not be dealt with in detail. In 1936–37, with a revised technique, we obtained similarly 41 records on the Bremen Line, 24 on the Copenhagen Line, and 32 on the Rotterdam Line, the first two lines being extended during 1937 to include certain coastal waters for a better definition of the limits of patches of plankton (from the Humber Light-vessel to the Norderney Light-vessel, and to the Hanstholm Lighthouse respectively). No records were obtained on the Pentland Firth line during 1936–37, but in the place of that service, arrangements were made to intensify the southern survey by the addition of a line between the Sunk and the Graadyb Light-vessels on a London–Esbjerg service, 15 records being obtained during the two years.

During this period we have aimed at obtaining at least one record on each line for each month, but occasionally this has been impossible owing, in various instances, mainly to mechanical defects in the recorder, bad weather, and to alterations in the sailing schedules of the steamships. On the other hand, in some months more than one record has been obtained on the Bremen and Rotterdam lines, particularly in the autumns of 1934 to 1937, when intensive programmes were deliberately arranged (in conjunction with the work of the Ministry of Agriculture and Fisheries Laboratory at Lowestoft) to provide information about the movements of patches of phytoplankton during the autumn herring fishery in the Southern Bight.

The mechanical principle of the plankton recorder is described in 'Bulletin' No. 1 and in greater detail in the '*Discovery* Reports' (Hardy, 1936*a*). Briefly, the plankton is collected as a sandwich between two moving bands of silk netting (60 meshes to the inch), one of which is divided into 2-in. sections, each corresponding to a known distance through which the machine has been towed. In the 1932–35 records the machine has been towed 1½ to 2 miles whilst one section was passing across the water-tunnel, *i. e.* collecting plankton; in the later records we aimed at a mileage ratio of 5 miles per section (the more exact calculations of the individual mile per section ratios are shown for each record in the List, 'Bulletin' No. 2). After various periods of storage in the laboratory an analysis of the plankton on each section[1] has been made, and for the phytoplankton this at first comprised the examination of a number of microscope fields amounting to $\frac{1}{150}$ of the area of the section. The resulting totals per section have been used in compiling the graphs for the earlier years; in the later years, however, when working at an approximate ratio of 5 miles per section, the method has been modified in order to provide standard estimations of organisms per mile in blocks of 10 miles. The silk has been examined in essentially the same manner, but the areas examined are smaller, and are adjusted according to the slightly varying ratios. The relative merits of these two methods will be discussed more fully in 'Bulletin' No. 4 and are referred to here on p. 86. The change also involved a change in the volume of the water passing through the machine (see p. 41 of 'Bulletin' No. 1).

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[1] There are also two other Bremen records for September and October, 1931, and two Copenhagen records for January, 1932. These were preliminary records obtained whilst testing the early models of the present type of recorder and, owing to the large period separating them from the others, they will only be referred to occasionally in comparison with those months of the later years. The number of records here mentioned is more than that in 'Bulletin' No. 4; this is so because many of the records of the intensive autumn programmes were obtained and analysed for the phytoplankton only.

After the counting process on the silk the plankton was scraped off (a process which has obviously involved some loss, most appreciable in the phytoplankton), and then preserved in tubes from which samples were drawn for checking purposes during the earlier years. Such analyses will be referred to as "tube analyses" in distinction from the "roll analyses". We have obtained, in addition, a relatively small portion of plankton from the formalin tank fluid in which the record was stored in the machine. This has been termed the "tank residue", and has on certain occasions provided evidence of material which has been missed on the roll, or, owing to the relatively better condition of the material, has allowed more detailed identifications to be made.

In the earlier part of the work we attempted to identify all the species of Rhizosolenia and Biddulphia, paying particular attention to *R. styliformis* and *B. sinensis*. Of the other diatoms usually only generic identifications were made, although in many instances these amounted to specific identifications with certainty. Estimates were also made of the numbers of Dinoflagellates as a whole, and of the volumes of Phaeocystis. In the later years it was possible to extend these a little, and in particular to separate from the rest of the Dinoflagellates the Biceratia (almost entirely *Ceratium furca*) and *C. fusus*. Other flagellates, etc., have been identified at various times, but they will not be dealt with in this preliminary work.

Planktologists used to more orthodox types of analysis and, in particular, systematists may think it unsatisfactory that specific identifications were not made throughout the work. There are reasons for this. At first the recorder was considered to be on its trial as a means of showing simply the changes in the broad features of the plankton. Also, only a minimum of time was available for analysis since the staff were largely occupied with another branch of the work—

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[1] A few of the Copenhagen records have only been analysed on alternate sections. There is reason for believing that little loss in precision has resulted from this abbreviation (see also p. 84).

that of correlating the plankton with the changes of the herring fisheries by experimenting with the Plankton Indicator, this being regarded as an important preliminary to the survey (p. 6, 'Bulletin' No. 1). Thus the earlier results had to be treated in only the broadest way; whilst some of the diatoms were dealt with in detail, others were only estimated on a broad scale and the Dinoflagellates were considered only as a group. Yet again, as will be shown later, the analysis of the recorder material has presented many problems which are not encountered in other types of survey; we have had to make the choice between detailed work with a few samples and much more extensive work on a broader scale. Certain phytoplankton forms (fortunately already known to have great practical importance), *e.g. Rhizosolenia styliformis*, can be identified and counted with greater accuracy and ease than others, whilst many of the (usually smaller) forms are much more difficult to deal with in the conditions of the work, and have had to be dismissed more briefly for the sake of time economy. We must not, however, assume that such forms are of less importance than some better-known species, and we hope that later, due to reorganization of the work, we shall be able to investigate the ecology of a larger number in some detail. The results obtained in 1938 have shown that much more detailed work may be possible in some groups.[1]

THE LIMITATIONS OF THE METHOD.

In his introduction Professor Hardy has outlined certain of the limitations peculiar to this method of collection, and has assessed their demerits in comparison with the advantages which it provides. Here further consideration will be given to those concerning the phytoplankton. It must be clear that for a number of reasons, any machine designed to take continuous records over an appreciable area and for long periods must necessarily sacrifice some of the advantages obtained with more usual apparatus. These sacrifices seem to concern (1) the methods of collection, and (2) the methods of dealing with the large quantities of material collected. Taking the second factor first, it will be clear that it is impossible to examine the vast number of samples in the intensive manner which might otherwise be desirable and which is obtained in other branches of plankton sampling. Up to the end of 1935 some 25,000 miles of sea-water were sampled for the phytoplankton, in 1936 and 1937 another 20,000, and the new programme of work (see p. 168) aims at some 2500–3500 miles per month as a minimum, with more detailed surveys in particular seasons and areas. The 25,000 miles up to the end of 1935 represent some 15,000 sections of plankton for analysis, and to examine these sections for all the groups has only been possible by a more cursory method of examination than is customary. This has had the result that at least in some of the preliminary surveys, errors of enumeration and identification have appeared, as will be seen on p. 79. These errors have been corrected where possible (see also footnote on p. 116); elsewhere the unsatisfactory material has been discarded, or if used (as in some types of numerical error), it is only with qualifications regarding the validity. By reorganization of the work in the future we expect to be able to avoid a number of these errors, but there is little doubt that some peculiar difficulties in identification will remain a feature of this type of work.

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[1] Gran, Hentschel and Russell (1936) have briefly discussed the problems of general plankton surveys and have made the point that it is not always possible to give that attention to detail which the specialist can give. In the later work we have made an attempt to come nearer to the requirements of their list in some of the groups, although certain modifications have necessarily to be made.

The effects described may also be associated with the other type of disadvantage—that due to the method of collection. In order to obtain the maximum material of various types with the minimum of expense within the time available, it has been necessary to use throughout the work a standard mesh of silk and to tow the machine at a constant depth. The silk used on the recorder has 60 meshes to the inch, and thus is a grade which would not normally be used for phytoplankton. In this work, however, we have had to use a mesh, which would serve for the sampling of both the zooplankton and the phytoplankton, and an intermediate grade had to be adopted. Some idea of its catching power is given by the list in Table I of the types of diatoms which have been collected during this survey. For the area investigated this may be regarded as fairly representative, but some digression may be fitting here to discuss briefly the collection of phytoplankton by means of nets in its relation to the recorder work. Early attacks were made on the validity of samples collected by any system of nets (the arguments of Lohmann, amongst others, will be sufficient to recall these), and more recently Nielsen (1933 *et al.*) and Russell (1935) have emphasized their defects with particular reference to the nannoplankton and the microplankton respectively. The former even goes further, with some justice, to attack the validity of estimations following the use of the centrifuge. With reference to the present work, Nielsen has rightly pointed out that it is not possible to estimate the total production of the smaller phytoplankton forms by means of the silk mesh in use—that it is even doubtful whether one can obtain this for the larger forms—and this difficulty has been realized from the start. There is, in fact, a growing agreement that an estimation of total production can never be obtained by means of any mesh which could be constructed owing to (1) the small size of some of the important producers, and (2) the problems of filtration at the lower limits of mesh size. Yet it remains doubtful whether any of the critics would suggest that all the samples which have been obtained by the use of nets, etc., have been of no value, although from time to time it appears necessary to insist that the real value of such work can only be realized after more appreciation of its limitations.

Particularly does this apply to the results appearing in the recorder work. With this machine we can obtain widespread and almost simultaneous surveys over an important area, giving, we believe, after consideration of its limitations, important indications of the distribution of plankton forms. With regard to the phytoplankton, at least, we know that it cannot measure the *total productivity.*

But, on the other hand, we believe that with some of the larger forms (*R. styliformis*, *B. sinensis*, and some of the Ceratium spp.) we can obtain records of their abundance which will compare directly with those obtained by tow-nets, whilst other aspects of the work suggest that the methods may also yield important estimates of the varying production which cannot so easily be obtained by other methods. Further

TABLE I.—*List of the Diatoms Recorded in the* 1932–37 *Survey.*

Melosira Borreri Greville.
Paralia sulcata (Ehr.).
Hyalodiscus steliger Bailey.
Coscinodiscus spp.
Actinoptychus undulatus (Bail.).
Asteromphalus spp.
Thalassiosira Nordenskiöldii Cleve.
,, *decipiens* (Grun.).
,, *gravida* Cleve.
,, *baltica* (Grun.).
Coscinosira spp.
Lauderia spp.
Schröderella spp.
Bacteriosira fragilis Gran.
Skeletonema costatum (Greville).
Stephanopyxis turris (Greville).
Detonula spp.
Dactyliosolen spp.
Leptocylindrus danicus Cleve.
,, *minimus* Gran.
Guinardia flaccida Castr.
Corethron criophylum Castr.
Bacteriastrum hyalinum Lauder.
Rhizosolenia alata Brightw.
,, *delicatula* Cleve.
,, *faeröense* Ostenf.
,, *fragillima* Bergon.
,, *Stolterfothii* H. Pérag.
,, *robusta* Norman.
,, *Shrubsolei* Cleve.
,, *setigera* Brightw.
,, *styliformis* Brightw.
,, *hebetata semispina* (Hensen).
Chaetoceros spp.
Biddulphia aurita (Lyngb.).
,, *mobiliensis* (Bail.) Grun.
,, *regia* M. Schultze.
,, *sinensis* Grev.
,, *granulata* Roper.
,, *rhombus* (Ehr.) W. Sm.
,, *obtusa* Kützing.
,, *favus* (Ehr.).
,, *alternans* (Bail.) Van Heurck.
,, *vesiculosa* (Ag.) Boyer.
Bellarochia malleus (Brightw.) Van Heurck.
Cerataulus spp.
Cerataulina Bergonii H. Pérag.
Lithodesmium undulatum Ehr.
Ditylium Brightwelli (West.).
Eucampia zoodiacus Ehr.
Streptotheca thamensis Shrubs.
Fragillaria spp.
Asterionella japonica Cleve & Möller.
Thalassiothrix longissima Cleve & Grun.
,, *Nitzschioides* Grun., Van Heurck.
Grammatophora spp.
Lycmophora spp.
Navicula spp.
Gyrosigma spp.
Bacillaria paradoxa Gmel., Van Heurck.
Nitzschia closterium (Ehr.).
,, *seriata* Cleve.
Nitzschia spp.
Surirella spp.

we may say, as was said of the plankton indicator (Hardy, Henderson, Lucas and Fraser, 1936), that if it is possible by these methods to obtain useful correlations, these correlations and their applications will hold good in spite of any disadvantages due to the method. We hope to be able to show that the advantages of this type of survey are likely to outweigh the disadvantages.

It will be advisable to indicate in further detail the types of error which may arise by the use of the recorder method. It is clear that forms smaller than the mesh of the silk (*i. e.* most phytoplanktonts) will be lost to some extent. On the other hand, we find that the recorder does in fact collect from time to time most of the forms found in this area ; the list of diatom species appearing in Table I will show how representative the collections are qualitatively. There seems little doubt that the smaller forms are only caught if present in fairly large numbers, when they adhere to the silk ; they may also be caught because of the presence of numbers of another form which are effectively reducing the size of the mesh. Again, whilst it is not surprising that the larger forms may be caught in numbers sufficient to clog the silk and to colour it green, it is a fact also that the smaller ones may do this at times, even in relatively pure communities. From these considerations it follows that the presence of small numbers of many of the forms must be regarded only as evidence of their presence with its obvious but limited value, the greater numbers being regarded as evidence of patches of importance. We must realize also that when clogging has occurred—as in all collections obtained by means of nets—the numbers caught must be minimal ; in other words the filtration will be more or less reduced.

Two other points remain to be considered regarding the position of the samples in space. These are (1) for the period dealt with here the limitation of the series of samples to relatively widely separated and divergent lines through a large area, and (2) the limitation of the samples to a fixed depth. Although the machine is a continuous recorder, it can only record along *lines* through the sea, and for reasons of economy these lines must be fairly widely spaced. This, whilst a necessity in the earlier stages of the work, is not a defect inherent in the method, and elsewhere an attempt will be made to show in the present work the relationship between the different lines, and how in the future more intensive recording can overcome the difficulties of discontinuity. The chief problem arises in the matter of tracing the identity of patches as they move along the lines from one record to the next, and also from one line to another. Whilst in many instances the configuration of the patch is helpful, further help can be obtained from consideration of the general constitution of the local phytoplankton complex. We are also exploring the problem of identity from the point of view of cell size taken by Wimpenny (1936) for the species of Rhizosolenia.

The limitation of sampling to one depth is more serious in the opinion of the writer, and can in the end only be answered satisfactorily by comparison of our findings with those obtained by other methods in an area at the same time. In the early stages of the work where economy has been essential, it must be remembered that we have had to adopt a compromise in order to collect organisms of various habits with one machine at one time, and the depth of 10 metres was chosen for this purpose. This is obviously not the most suitable depth for all the forms which have been collected, and the various defects will be discussed in the appropriate sections. Reference to 'Bulletin' No. 1 (p. 50) will show that a new device is being considered which may to some extent solve the difficulty by fishing throughout a vertical plane of water; it will also be clear that if funds were available it could be solved by the use of more machines at the same time, or at very short intervals.

TABLE II.—*Comparing Horizontal Hauls between 5 and 25 metres with Vertical Hauls at the Same Station (from Savage and Wimpenny,* 1936). *Values are given in units of one thousand cells. Figures in heavy type are for stations between 5 and 15 metres. The indices denote the number of samples when greater than one.*

R. styliformis		*B. sinensis.*	
Horizontal net.	Vertical net.	Horizontal net.	Vertical net.
0^{2}	0	0^{3}	0
0^{3}	**0**	**0^{2}**	**0**
100	12	4	1
108	33	45	8
196	17	**76**	**0**
300	**26**	**215**	**8**
1550	102	1449	267
8512	**159**	1623	131
17,850	**420**	**4,830**	**352**
22,300	1,091	**6,000**	**137**
26,324	**420**	**10,950**	**376**
27,000	**796**	**42,300**	**1,417**
33,600	1,377	44,200	1,938

With regard to the phytoplankton, however, it will be realized that the depth of 10 metres is a significant one, being through a zone of active photosynthesis under normal conditions in the area. We may also consider that in the North Sea (and particularly in the Southern Bight), owing to the relatively shallow depth of water and the generally turbulent conditions, the distribution of the phytoplankton is less likely to vary markedly from layer to layer as it is in deep waters. Evidence on this point is to be found in the work of Savage and Wimpenny (1936) in this region during the years 1933–34. On pp. 52–59 (*loc. cit.*) they show graphs of the vertical distribution of the phytoplankton at different stations in a number of cruises, and it is evident that while the distribution may vary from time to time (the densest zone may be in mid-water, at the surface or at the bottom), yet, in general, a record taken at a depth of 10 metres would on any one cruise have provided an adequate measure, for comparative purposes, of the production over the whole depth. Reference also to the paper by Savage and Hardy (1935) show comparable results for the same organisms and also for the flagellate Phaeocystis.

TABLE III.—*Comparing Mid-water Horizontal Hauls with the Means of Surface, Mid-water and Bottom Hauls at the Same Stations (from Savage and Wimpenny,* 1936.) *Values are given in units of one thousand cells. Figures in heavy type are for stations between* 5 *and* 15 *metres. The indices denote the number of samples when greater than one.*

R. styliformis.		*B. sinensis.*	
Horizontal net.	Mean S.M.B.	Horizontal net.	Mean S.M.B.
0^{24}	0	0^{3}	0
0^{9}	**0**	**0^{2}**	**0**
0^{2}	+ to 1	0^{5}	+ to 1
0^{4}	**1 to 5**	+ to 7^{12}	+ to 7
+ to 6	+ to 3	**1 to 10^{7}**	**0 to 31**
+ to 10	**1 to 31**	16 to 39^{5}	8 to 54
30	**20**	**10 to 38^{6}**	**13 to 34**
71	72	52 to 98^{4}	30 to 183
74	61	**75^{2}**	**100 to 170**
74	**64**	**105**	**101**
105	**67**	**107**	**74**
413	**198**	113	50
4,650	**2,637**	**150**	**164**
5,250	**7,650**	**189**	**242**
5,850	**3,570**	263	113
6,075	**9,975**	**267**	**90**
6,083	3,694	**375**	**208**
8,025	5,933	375	184
12,750	**9,967**	**450**	**165**
14,250	**8,058**	**600**	**555**
		675	**343**
		720	**845**
		725	1,599
		812	2,769
		1,260	2,113
		1,590	**606**
		1,725	**1,367**

We can investigate this relationship in more detail by consideration of the actual findings of the numbers of *R. styliformis* and *B. sinensis* taken in mid-water horizontal hauls, and also in vertical hauls at the same stations (Savage and Wimpenny, 1936: tables xvi to xxxviii). In our Table II we have compared 16 mid-water hauls between 5 and 25 metres with the corresponding vertical ones.[1] Whilst there is not a perfect agreement in proportion between these pairs of figures —we could hardly expect it—yet the corresponding members of any pair are found to be of the same order in proportion to the other members of the pairs, suggesting that on a survey by means of horizontal hauls at these levels, the resulting idea of the distribution would have been similar to one obtained by means of vertical ones. There is further evidence to the same end, since Savage and Wimpenny's data also enable us to compare some 60 midwater horizontal hauls which were between 5 and 25 metres with the means of the series of surface, midwater and bottom hauls made together. This is shown in Table III and a similar degree of proportionality is shown, since the 5–25-metre hauls are clearly of the same order as the means of the three hauls and never are there any serious divergencies. It would seem reasonable that we should assume that the 5–25-metre hauls are fairly comparable with those samples obtained with the recorder, but an even closer approximation can be found from the figures in heavier type in these two tables, these being limited to hauls between 5 and 15 metres. The only differences in the proportions between these comparable hauls are no larger than the differences found by other workers when collecting pairs of samples simultaneously under as far as possible identical conditions (*e. g.* Herdman, 1923). The latter differences may be very large, and whilst due partly to defects in the methods of collection, they arise probably in extreme patchiness over small areas in the sea. They are undoubtedly larger than the errors from random sampling which are common to most methods of plankton analysis, and to which it is probable that many of the divergencies in Tables II and III may be due. For these various reasons, then, we feel justified in thinking that we are likely with horizontal hauls at 10 metres to be able to survey the phytoplankton with results comparable with those obtained by means of the orthodox vertical nets. The fact that phytoplankton taken appreciably below this level is more likely to be moribund than actively photosynthetic should add to the realism of the results, and the ability to make the samples in a continuous series should yet further increase their value.

Such findings tend to increase confidence in the recorder as a sampling instrument, but in many ways the final and most important test lies in checking the findings of one method against those of another which has other peculiar advantages and disadvantages—in this instance, sampling by means of vertical hauls with conical nets. We are able to do this within certain limits, by comparison of our records with the distribution of phytoplankton sampled by the Ministry of Fisheries' Research Ships *George Bligh* and *Onaway* at similar times and over a neighbouring area. The limits to such checking are very definite unless deliberate tests are arranged (which so far has not been possible), and seldom have we had samples at the same time and place as those of the Ministry's ships, so that, in order to provide a reasonable number of comparisons, we have in some cases to consider data separated by as much as 14 days,[1] and including stations some miles distant from the recorder line. An idea of the relationship between results obtained by this method and during the usual plankton surveys can be obtained by comparison of our figures with those of Savage and Hardy (1935) and Savage and Wimpenny (1936), but it will be profitable to discuss one or two examples in more detail.

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[1] In the course of abstracting from the original tables some slight alterations have been made, such as to provide standardized times (10-minute hauls for Table I and 5-minute hauls for Table II).

From a qualitative point of view the correspondence is very good, and rarely do the methods disagree in recording the presence or absence of either *B. sinensis* or *R. styliformis*, but whilst most of the comparisons from a quantitative point of view are proportionate, here and there are striking disagreements, particular examples occurring in November, 1933, and the period 22nd–29th October, 1935.[2] Of these the first may well be due to the large discrepancy in date (over ten days), but the second figure shows that towards the eastern end of the line when the recorder was collecting very little Rhizosolenia, within a reasonably short time a very large sample was obtained by means of vertical nets in almost exactly the same place. The result is that the recorder finding would undoubtedly suggest this diatom to be very scarce at the eastern side, while the more orthodox method (admittedly on the evidence of one station) leaves us with the impression that it is certainly not scarce, and possibly abundant.

In the final discussion some aspects of the patchiness of the phytoplankton are considered. Hardy (1936*b*) has already shown examples of the type of patchiness which the method of continuous recording has revealed, and the present survey shows more fully that whilst at times the phytoplankton may be fairly smoothly distributed, at other times there may be a very pronounced patchiness. Amongst many others, the Bremen line record for the 2nd October, 1935, is a good example, see Text-fig. 1 (A) ; the recorded distribution shows the bulk of the *B. sinensis* to be in the east, as Rhizosolenia is in the west, but the latter has a very striking patch near the middle of the record, and the former had a small but dense zone towards the western end. In Text-fig. 2 this graph has been analysed and treated in different ways. In the first derived graph the values for every tenth section have been plotted, and it is clear that by omitting some of the analyses in a regular manner it is possible to miss some of the essential features of the record. In the subsequent graphs the other nine sets of tenth sections are shown and, as might be expected, the results vary considerably. Some provide graphs differing little in essence from the complete one, but most of them show more or less serious divergencies, thus emphasizing the "patchiness" which occurred at that time. Similar results would have been obtained by the use of a tow-net at (in this case) 16-mile intervals. The series of graphs shows that by starting at different points very different ideas would be obtained of the distribution of Rhizosolenia over a distance of 100 miles, and some would be quite erroneous.

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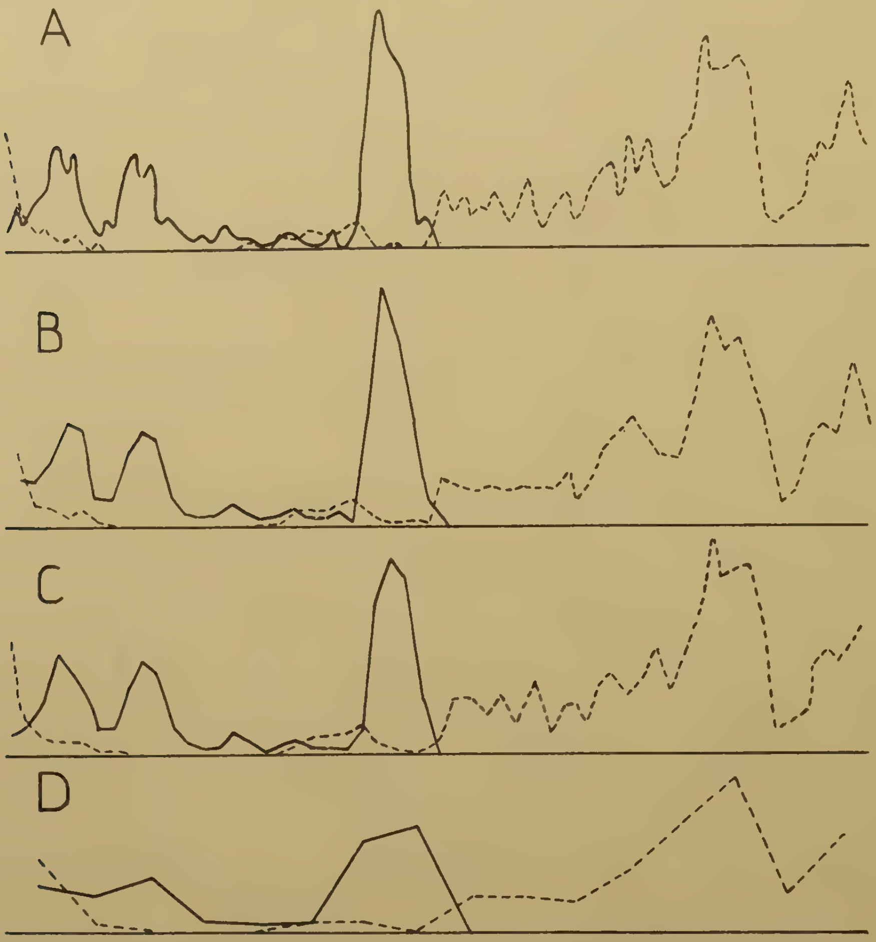
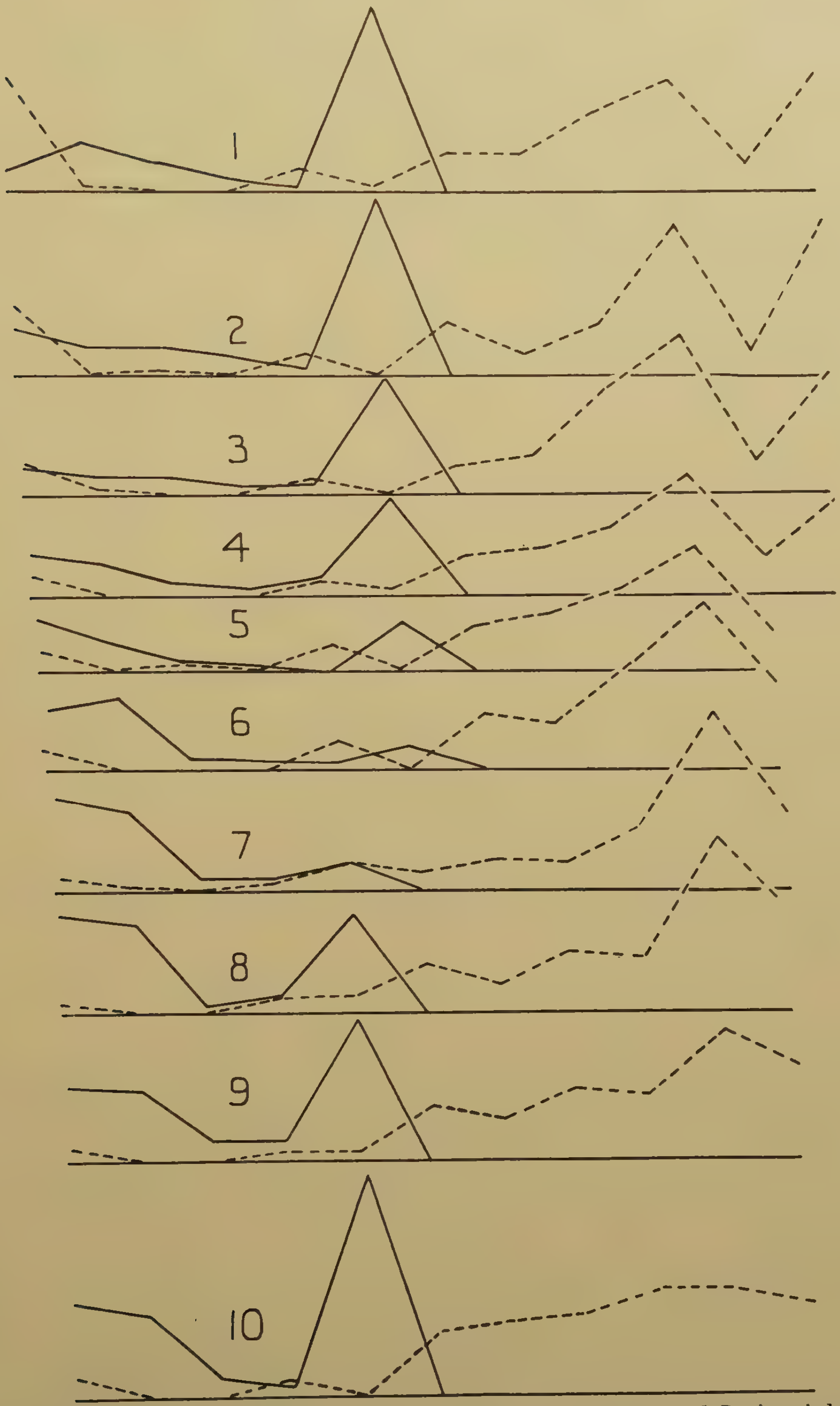
[1] Reference to Text fig. 17 will give some idea of how large a difference may be found in the distribution of the phytoplankton at 10 metres within a few days. The results of Savage and Wimpenny show similar changes within a short period of time.

[2] We should like to take this opportunity of thanking Mr. R. E. Savage and Mr. R. S. Wimpenny, of the Ministry of Agriculture and Fisheries, for their kindness in allowing us to see in advance some of their unpublished data for the distribution of *R. styliformis* and *B. sinensis* since 1934.



Text-fig. 1.—Graphs of *Rhizosolenia styliformis* (continuous line) and *Biddulphia sinensis* (broken line) recorded for the Bremen line on 2nd October, 1935: A, by plotting values for every section; B, by plotting values for every alternate section, i.e. 1st, 3rd, etc.; C, also for every alternate section, but 2nd, 4th, etc.; and D, the whole data arranged in units of *ca.* 10 miles each.

Along with the original detailed record in Text-fig. 1 (A) two other treatments have been adopted. In the first (graphs B and C) the two alternative groups of first, third, fifth, etc., and second, fourth, sixth, etc., sections have been plotted to show that by the omission of alternate sections there would in general be little loss of detail (see p. 75). In the second method (graph D) the whole data has been *averaged* in blocks of about 10 miles, and it is clear that here the only disadvantage



Text-fig. 2.—The same record as in Text-fig. 1 (*R. styliformis* continuous line and *B. sinensis* broken line), but shown by plotting the values for every tenth section. The series of graphs 1 to 10 shows the differences obtained by starting to plot at the 1st, 2nd, 3rd . . . or 10th sections respectively.

is that due to the decrease in definition arising from the necessary "smoothing" (see also p. 90). It is impossible to treat this subject here in further detail, but the general findings have convinced us that when, in the extended survey, it became necessary to decrease the work of analysis, we should be justified in adopting a modification of this method, providing automatic "smoothing" by altering the mile per section ratio to one of 5 miles per section, and arranging the analyses to give estimates for blocks of 10 miles, or approximately two sections. The subject will be discussed more fully by Mr. Rae in 'Bulletin' No. 4.

It seems very probable that patchiness of this nature is partly the cause of such marked discrepancies as have been found between recorder findings and more usual methods. Marked patchiness may be found fairly frequently according to the recorder analyses (see p. 154), and it may be that the disagreement quoted above for the period 22nd–29th October, 1935, was due to the fact that the tow-net sample was taken in the middle of a small patch which had either moved off the line of the recorder in the fairly short period separating the two observations, or that at the very time that the line was sampled by the recorder there was nearby a dense patch which happened to be sampled by the other method.[1] From this it will be evident that here is implied a criticism of both methods. Many of the stations worked in the normal manner by means of a tow-net from a research ship are more than 25 miles apart, and it is clear that under such conditions significant patches may be missed and a false idea of the general distribution may be obtained; similarly the importance of a small patch may be exaggerated. On the other hand, whilst *along the line of the record* the recorder method gives a continuous sampling and so omits no patches, yet it may in a similar manner miss patches which are quite close to the line and similarly give a false impression. The results so far suggest that for some time the two methods must be regarded as complementary. We feel that the recorder surveys have opened up a new field of research by very speedy and economical methods, but it is clear that very much more value can be obtained from its findings when worked in conjunction with the older methods.

The Significance of the Data.

We have felt it necessary to describe at some length the various disadvantages of this new method of research in order that a full realization of its limitations should be available from the beginning. Some of these may prove to be unavoidable in this type of work, whilst others have arisen as a result of the difficulties inherent in the earlier stages of a large scale survey when somewhat broad methods had to be adopted. A few of these problems were overcome during the interim period 1936–37, and since the beginning of the extended survey of the whole of the North Sea, we have been able to overcome more of them. Throughout the work we are trying to bear in mind the limitations imposed by the method, and to present the data only in a form which is fully justified.

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[1] Further evidence on this point is, in fact, provided by the recorder material. Some days before the record referred to a dense but narrow patch appeared in this region (*cf.* the data for Text-fig. 1); this was apparently off the line when the next record was taken, presumably having moved a little, although it might well have been sampled within a very short distance from the recorder line. In the continuous series of records (see Text-figs. 3 and 4) this type of change often occurs and in practice our experience shows how extremely dangerous it may be to consider isolated samples, the actual on the contrary, being only appreciated as a dynamic condition.

We shall consider here only the more precise data for *R. styliformis*, *B. sinensis*, the Dinoflagellates and Phaeocystis. The remarks will apply even more obviously to the other forms which will be more summarily presented, although in the future we hope to be able to present some of these forms with similar precision. All graphs are based upon the figures as actually found during analysis, and no attempt has been made to smooth out any irregularities in the curves (apart from the smoothing involved by the mechanical action of the machine, see 'Bulletin' No. 1, p. 36). It will be seen that most of the graphs are rather irregular and it is important to realize the significance of these irregularities—a feature which has been discussed from another point of view on p. 155. As is well known, the process of sub-sampling by any method during the process of analysis introduces a random error into the estimations. This is involved in the recorder work as a result of counting only random portions of the plankton on each section. In addition it is also well known that the distribution of the plankton in the sea may be such that even over a small area it is difficult to obtain samples of exactly similar constitution (amongst others, Herdman (1924) took samples from tow-nets towed from each quarter of the ship and obtained differences of a fairly high order between them). For these two reasons alone it is evident that we should not lay great stress on the smaller fluctuations in the graphs, some of which may undoubtedly be due to random errors of this sort and which together, there is reason to believe, may amount to as much as ±50% of the true value. It is clear that only the larger fluctuations should be regarded as truly significant—perhaps we may include safely all those which show between consecutive sections differences of the order of × 3 and upwards. Yet this is not to say that smaller variations do not occur between the larger scale patchiness which is amply demonstrated by the recorder method (see p. 156 and Hardy, 1936*b*) and the very small spatial variations suggested by Herdman. We have good reason to believe that there will be significant patchiness over small distances of (say) $\frac{1}{10}$–1 mile, and it would be of interest to investigate these at some time by means of a recorder working with a very small mile per division ratio—say 20 divisions to 1 mile.

Again, on p. 79 we have referred to another aspect of the material. Samples will tend to be mainly minimal for the reasons discussed there, the smaller numbers of most organisms being necessarily low as the result of losses due to the size of the mesh, whilst the largest numbers may also be low from the effects of clogging. It is probable that at least in part the discrepancy in order between our findings and those of Savage and Wimpenny (1936) may have arisen in this way, and it should be realized that most of the denser patches should probably be denser still, and further, because of this, that the extent of the patches (spatially) may be exaggerated—*i. e.* that patchiness may be even more pronounced than appears here (see also p. 156).

One thing remains which does not concern the peculiarities of this method. On p. 77 the point is made that the results from this or any other survey can only present an estimate of the " residual population " at any time—*i. e.* that " nett population " which remains from time to time after the effects of death from feeding of herbivores (or any other means) have occurred. This nett value should not be confused with the total production of any form or for any area, since this cannot directly be estimated by this method. Nor will the nett value necessarily give a *measure* of the total production or even the amount of food available for herbivores, as a simple hypothetical example should make clear. If we consider any form whose maximum rate of division is once per day, and minimum is once per 10 days (this should not be too extreme for some types of phytoplankton in different seasons), then although we might on sampling the water find an approximately similar quantity of the form throughout the year (the "nett" value), this clearly could not indicate a constant production since this might have varied markedly, yet, on the other hand, it would give no evidence regarding the amount of food which had been consumed, since we know from the hypothesis that this has varied from a yield of one unit per day per unit of catch to one unit in only ten days at different parts of the year. Certainly an example is not likely to arise in such a simplified form, but the possibilities of which this is an extreme case are such that we should be very wary of making deductions from the net stock regarding gross production, or of comparing productions at different times and in different areas; we need to know much more about the life of the phytoplanktonts themselves *and* of the biology of the forms which form their organic environment in the community. These matters are perhaps generally realized, but it seems seldom that they are made sufficiently clear.

Bearing these factors in mind we may say that the graphs which are shown in the following pages represent broad estimates of the minimal values of the " nett " residual stock of various forms from time to time along " lines " at 10-metre depth through the sea. It seems probable that only differences of the order of ×3 and upwards should be regarded as truly significant, although the whole series of samples should always be considered as a check on this. In considering them it must be realized that movements as well as growth processes can appreciably affect the distribution on any one line.

The Arrangement of the Data.

Whilst from one point of view the amount of plankton collected by the recorder is small, the method allows of the collection of enormous numbers of samples. In the period 1932–35 we have some 15,000 samples, each the equivalent (apart from bulk) of a horizontal net haul for a distance of $1\frac{1}{2}$ to 2 miles, and in the last two years some 2000 10-mile samples, a total of some 45,000 miles recorded. These have been taken over a small area at fairly regular intervals throughout 5½ years. The mere presentation of such data is a formidable task, and it might be done in several ways. It is necessary for economy to abbreviate this space as much as possible, and for this reason the data has been arranged mainly in a graphical manner, the text being reduced to notes emphasizing the more important and significant features of the graphs—points which will be referred to in later sections and papers—and the only tabular material consisting of abstractions from the primary data. There still remain two chief ways of grouping the material depending on the selection of routes or organisms as the basis of the arrangement. There are good reasons for the adoption of either of these, but on the whole it seems fitting to compromise and to discuss the data regarding each organism in turn, considering under these heads each of the lines, and subsequently attempting to relate them as a whole.

In an earlier section, discussing the relative validity of the material, we have found it advisable to divide this into two groups—the first to be dealt with in greater detail (*R. styliformis*, *B. sinensis*, total Dinoflagellates, *C. fusus*, etc., and Phaeocystis), and the remaining forms to be dismissed more briefly and according to the precision of the analyses. For the first group, of which the bulk of this paper will consist, the distribution of each form will be shown month by month by means of graphs, first on the Bremen Line, and then on the others in turn (the Bremen Line has provided the greater number of records, and so forms a basis to which the other data can be related, and it is suitably in the centre of the area), and then the results will be discussed for the whole area by reference to serial maps. In the third section of the paper various points arising from these data will be dealt with briefly, detailed discussion being deferred to later papers (by various members of the staff), in which different aspects of the 5½ years' results can be considered not only in relation to the phytoplankton, but in relation to the rest of the plankton and to specific marine problems. Whilst there are certain advantages in producing, as here, the results for several years in one paper, there are also disadvantages, the greatest of which concerns the delay in making known the data to other workers. Until now this has been unavoidable for a number of reasons, but from 1938 onwards we hope to be able to produce the data for each year as early as possible in the following year, and then, as the occasion provides, to produce general papers in which the various matters can be co-ordinated.

The graphs which have been used in presenting the data require some explanation, and since most of them will be arranged in a standard manner, much repetition may be avoided by outlining briefly here the methods which have been used. There are four main types for each organism of importance (*i. e.* of Group 1 above) on each line.

1. *Annual Route-distributions*: Plates I to XXI.

Each line (Bremen, Copenhagen, etc.) has been designed to run normally between two termini (usually light-vessels); occasionally a record may be short, owing to weather conditions or mechanical troubles (see List in 'Bulletin' No. 2), and sometimes they may be longer (in 1937 two of the routes, the Bremen and the Copenhagen, were deliberately extended), but in all records positions have been referred to these points as accurately as certain small limitations (outlined in 'Bulletin' No. 1) will allow. The numbers of each form per unit of distance have been graphed. In the first type of figure these graphs are arranged one above the other through each year according to the time-gaps between consecutive records. Thus we have in this arrangement an ordinate which can represent at the same time (*a*) a terminus for the line, (*b*) the passage of time, and (*c*) the quantity of plankton, whilst the abscissa represents distance from the termini. The data for each year have then been arranged consecutively, so that those for corresponding periods in different years may be compared as easily as possible. These graphs will form the basis for the description of the essential variations in position and of quantity of each form.

Whilst there have from time to time been changes in the aperture of the recorder (see 'Bulletin' No. 1, p. 43) and in the mile per section ratio, these figures are so arranged that the graphs shall be as nearly comparable as is possible. For 1932–35 the original analyses provided estimates of organisms per section, and from them could be obtained graphs showing numbers per section at intervals represented by the mile-per-section ratio. These cannot be exactly comparable *inter se*, but (see p. 74) the deviation from the average ratio (1·7 miles per section) rarely exceeds 10%, and this is insignificant compared with the much greater differences in quantity which have been found. The data for 1936–37, on the other hand, was analysed to provide immediately organisms per mile per 10-mile block; they are, of course, quite comparable *inter se*, and from now on this method will be adopted (see p. 86). By the simple process of modifying the scale for the 1932–35 data it is possible to make the whole sufficiently comparable for our purpose, so that within the limits specified all the graphs show approximately the numbers of organisms per mile, but whereas the earlier ones give observations for intervals usually less than 2 miles, all those for 1936–37 are automatically smoothed to provide 10-mile samples.

2. *Serial Charts*: Plates XXII to LXIV.

In order to co-ordinate the whole available data for each month, an alternative presentation has been adopted in which graphs obtained in the manner just described are traced on to charts of the area. It has not always been possible to show every record when more than one has been available on any line in one month and so representative ones have been chosen (*i. e.* those most nearly similar in date), and where it has been considered necessary, additional records are inserted on extra charts for comparison; elsewhere reference should be made to the graphs of Type 1. The charts are usually arranged so that six, representing half a year, appear on one page; the results for a whole year can be seen conveniently, and by turning consecutive pages the different years can be compared. The maps will be used to form the basis of discussions of the phytoplankton as a whole, in relating our findings to other work in the area, and in relation to possible movements involved in the temporal changes in position. For reasons of economy and for comparison, two forms have been shown together on each set of maps.

After the introduction of the extension to the C-line and the new Esbjerg line in 1936–37, it was necessary to use a rather larger map. This has modified the arrangement a little and in the autumn of 1937 we have only been able to include three maps to the page.

It will be realized that in the graphs of Type 1 from which the charts have been derived the mileage scales have been similar throughout, whereas on the charts the mileage scale should normally be a varying one (the charts have been derived from Admiralty Chart No. 2339). Consequently the base-lines need to be distorted, or else some slight inaccuracy in the positions is involved in retaining a standard base-line. In this work it has been more convenient to have the base-lines strictly comparable, and since the errors have been usually very slight (particularly so considering the extensive reduction in reproduction), this method has been adopted.

3. *Annual Variations, e. g.* Text-fig. 5.

For each of the graphs of Type 1 it is possible to obtain a series of "totals" for the quantities of phytoplankton found on each of the series of records. It will be realized that the quantities so found cannot be anything other than minimal for reasons which have been discussed on p. 79, and they are best defined as those quantities found from the beginning to the end of a record at a given time. On the other hand, for each form the factors affecting the quantity will be similar, within certain limits, from time to time, and it is felt that the sums so obtained provide at least some measure of the quantities in the sea. Whilst a quantity, "a", which is (say) three times as great as another, "b", may not represent exactly a ratio in the sea of 3 : 1, yet we should be reasonably sure that the flora giving rise to the sample "a" was larger than that producing "b", and that a similar ratio of quantities on another occasion might represent similar ratios in the sea. The larger changes in these quantities which are found to occur are, moreover, of such an order that their significance is the greater for this reason. It is essential to realize that these are merely *changes* occurring over the line, and may arise from the processes of growth, death and physical movement.

Throughout the survey the totals used will only represent the quantities found between the termini which were in use at the beginning; the extensions to certain lines in 1937 have been excluded so that the figures shall be as strictly comparable as possible. There are, however, a number of short records for which totals clearly may be low, but which may have some value. Unless they should produce higher values than their neighbours, records of less than half of a line have been omitted, and where more than 20% has been unrecorded the fact is indicated, and less reliance should be placed on such totals.

The resultant totals have been plotted against time to show annual variations in the records and variations between the different years. At times the quantities may be very greatly in excess of totals at other times when patches are small although, within their season, important, and for this reason two scales have been used to denote quantity: (*a*) the "normal" scale, covering the whole range and rising from the "true" base-line of the graph, and (*b*) a tenfold scale below the true base-line within which it is possible to see the variations due to small but possibly significant changes taking place when the form is not abundant. The general annual cycle should always be considered by reference above the true base, since the detailed changes taking place below this line are such that, on the normal scale, they would not be visible above it.

4. *Maximal Quantities, e. g.* Text-fig. 6.

A further set of charts has been used to show the largest quantities of the various forms which have been found on any part of the line during each year and during the whole period of the survey. Over a long period they should provide a set of standards for comparison of conditions from time to time, and may also be used to show clearly the areas in which the various organisms are found to live.

Other graphs and data will be derived from the foregoing and will be described where necessary, as also will specific modifications of the general methods outlined above.

It remains to describe the scales denoting the numbers of organisms. For Phaeocystis and the total Dinoflagellates a simple linear scale has been used, but for the diatoms and individual species of the Dinoflagellates it has been more convenient to use a variable scale, which shall at once indicate the thin patches, which are relatively significant on occasions, and yet provide suitable limits to the heights of the graphs (see plates and figures for examples). For these forms the same type of scale has been used throughout.

The Distribution of *Rhizosolenia styliformis* Brightw.

The distribution will first be considered briefly on each route, as illustrated in the series of graphs of the quantities of this diatom recorded month by month and in each year. This series enables one to compare more easily the seasonal variations throughout the whole period. Then, by means of the monthly maps an attempt can be made to relate the records from the different lines, so that the general character of the annual distributions can be summarized. A description of the arrangement of these charts has just been given.

The Bremen Line.

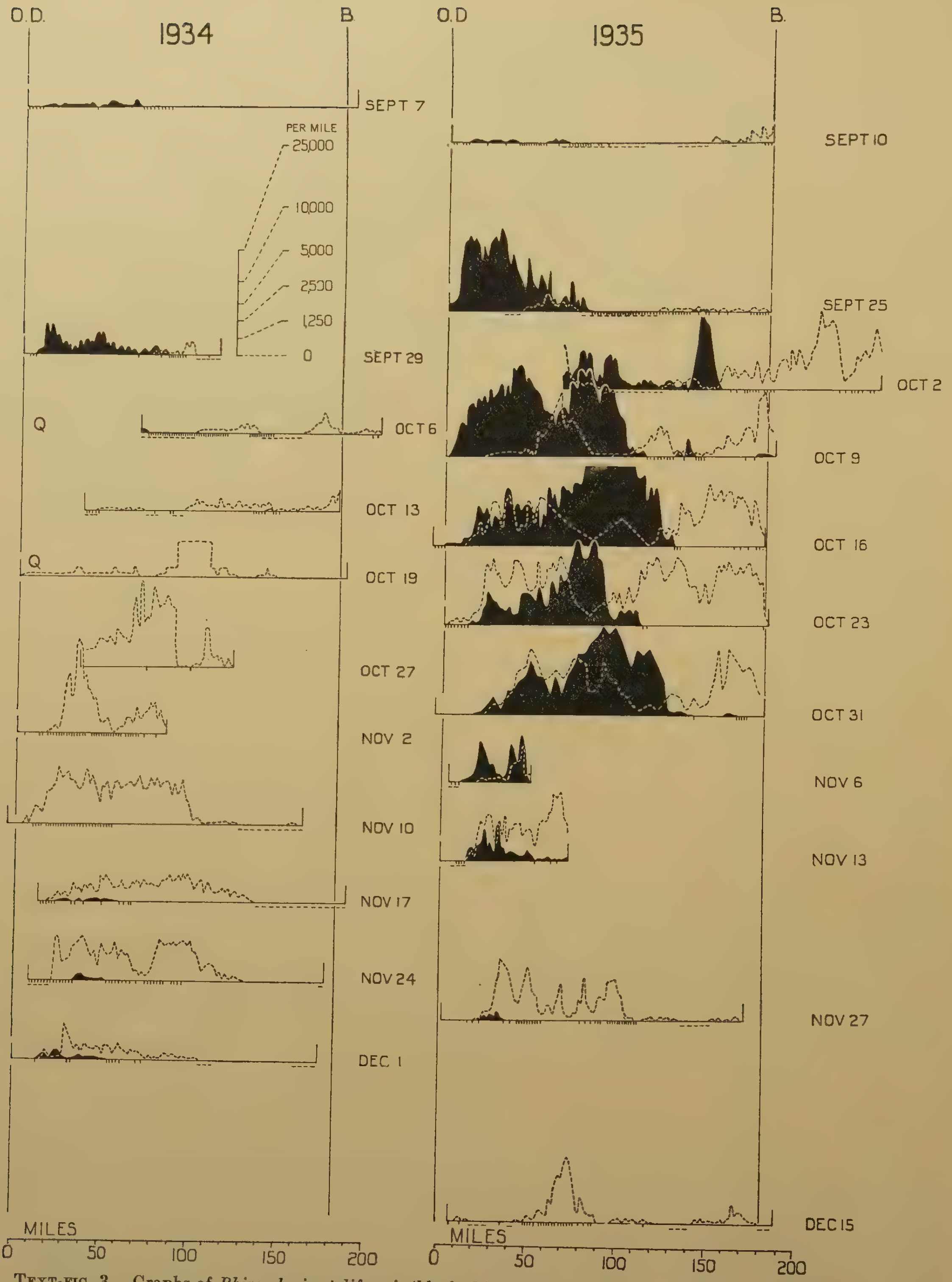
Representative monthly records for the period June, 1932, to December, 1937, have been arranged in Plates I and II, never more than two being shown for any month in order to prevent undue confusion of superimposed graphs. In the autumns of 1934–37 a more intensive programme was carried out, the records being shown graphically in Text-figs. 3 and 4 against an increased time scale. In both figures and plates the larger numbers of the diatom, forming well-marked concentrations, appear as blacked-in graphs above the line, whilst the smaller quantities, termed "traces", have been shown as small vertical strokes below the line. In the series of more detailed autumnal records (Text-figs. 3 and 4) it has been more convenient to combine the results with those for *B. sinensis*, the latter appearing as the broken-line graph and the traces being represented by horizontal strokes. Asterisks have been used to denote that the diatom was not seen during the silk-analysis. Occasionally (see List in 'Bulletin' No. 2) a record has been obtained which, although not as reliable as the others, has yet been thought to be of useful qualitative value; such records have been indicated by the symbol "Q".

Only the main features will receive comment here; others will be referred to later, and in future papers considering the results in relation to other factors.

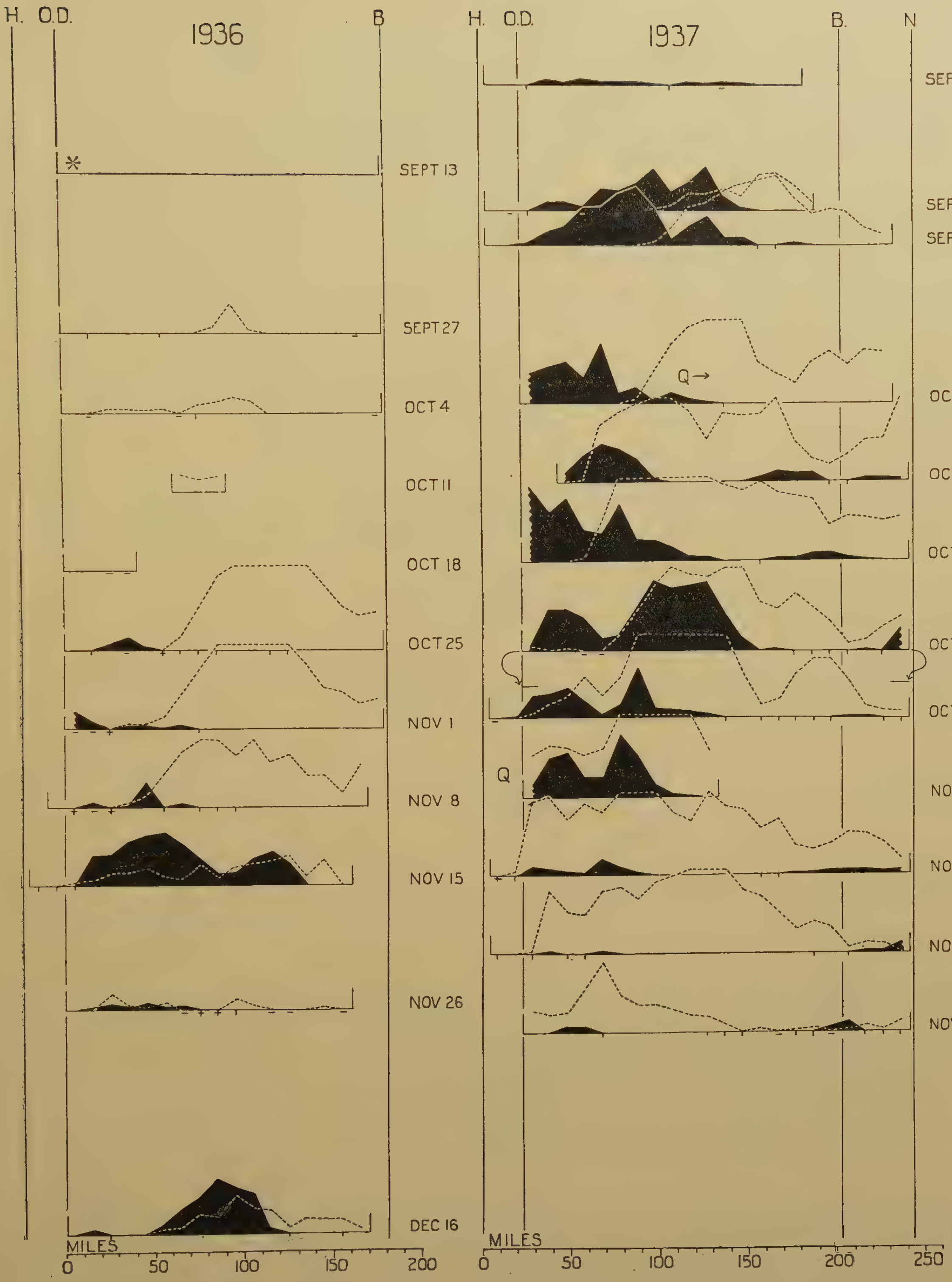
It is seen that the production is characterized by marked periodicity; patches are rarely observed in the months before August, but reach a maximum in September, October or November, and are normally small or absent in December. Within the main cycles there are annual variations. Whilst Rhizosolenia is generally scarce from January to June, in 1935 a patch occurred in early May, only to disappear again, except for traces, at the end of the month. More typically small patches have appeared in June and July, some disappearing before the onset of the autumn production, but others appearing to be connected with it.

The more significant differences have concerned the time of appearance, the duration and density of the autumnal concentrations, which have been considered to be so important in relation to the East Anglian herring fishery (Savage and Hardy, 1935, and Savage and Wimpenny, 1936). These are shown in some detail in the series of records in Text-figs. 3 and 4 for the years 1934–37, but for 1932 and 1933, when only monthly records were aimed at (and not always achieved), our knowledge is poorer. The lack of weekly records in these years has been unfortunate, and we realize that patches may have been missed as they passed across this route during the intervening periods, as the findings of Savage and Wimpenny (1936) suggest for 1933. Although the collection of weekly samples over a large area for very long periods is not likely to be feasible, we must realize that extensive changes may occur within one month; hence the necessity of recording at short intervals for certain purposes, which process should become less necessary as the number of recording lines can be increased.

Whilst in some years the general trend has led up to a maximum on this line

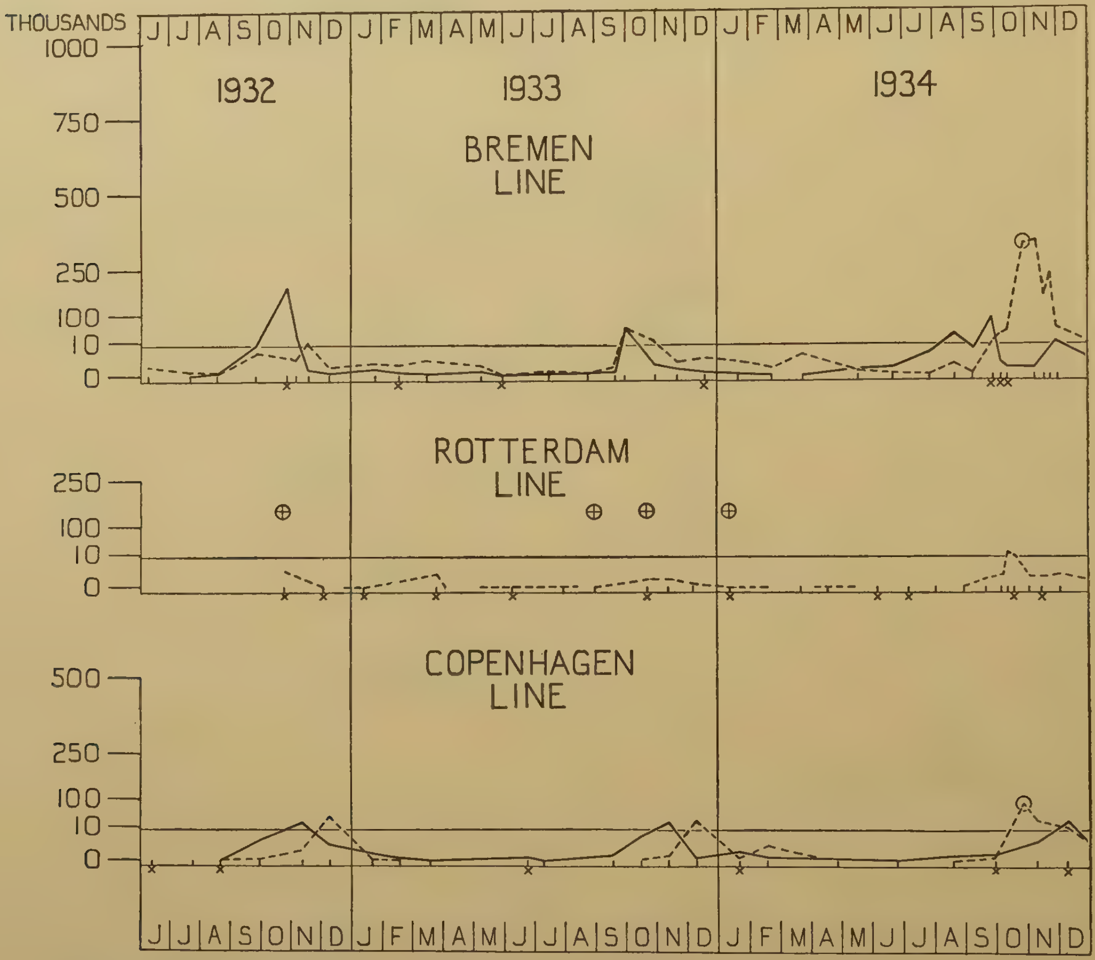


TEXT-FIG. 3.—Graphs of *Rhizosolenia styliformis* (blacked in) and *Biddulphia sinensis* (broken line) from records taken on the Bremen line during the autumns of 1934 and 1935. The vertical lines O.D. and B. indicate the positions of the Outer Dowsing and Borkum light vessels; they also represent a time scale from September to December against which each graph is placed in its appropriate position according to its date. Patches are shown above the base-lines (see scale above) and traces as small vertical or horizontal strokes below the line (*Rhizosolenia* and *Biddulphia* respectively). Data to the east of the sign "Q" may be mainly of qualitative value only. Records for the whole of the years are shown in Plates I, II, V and VI.



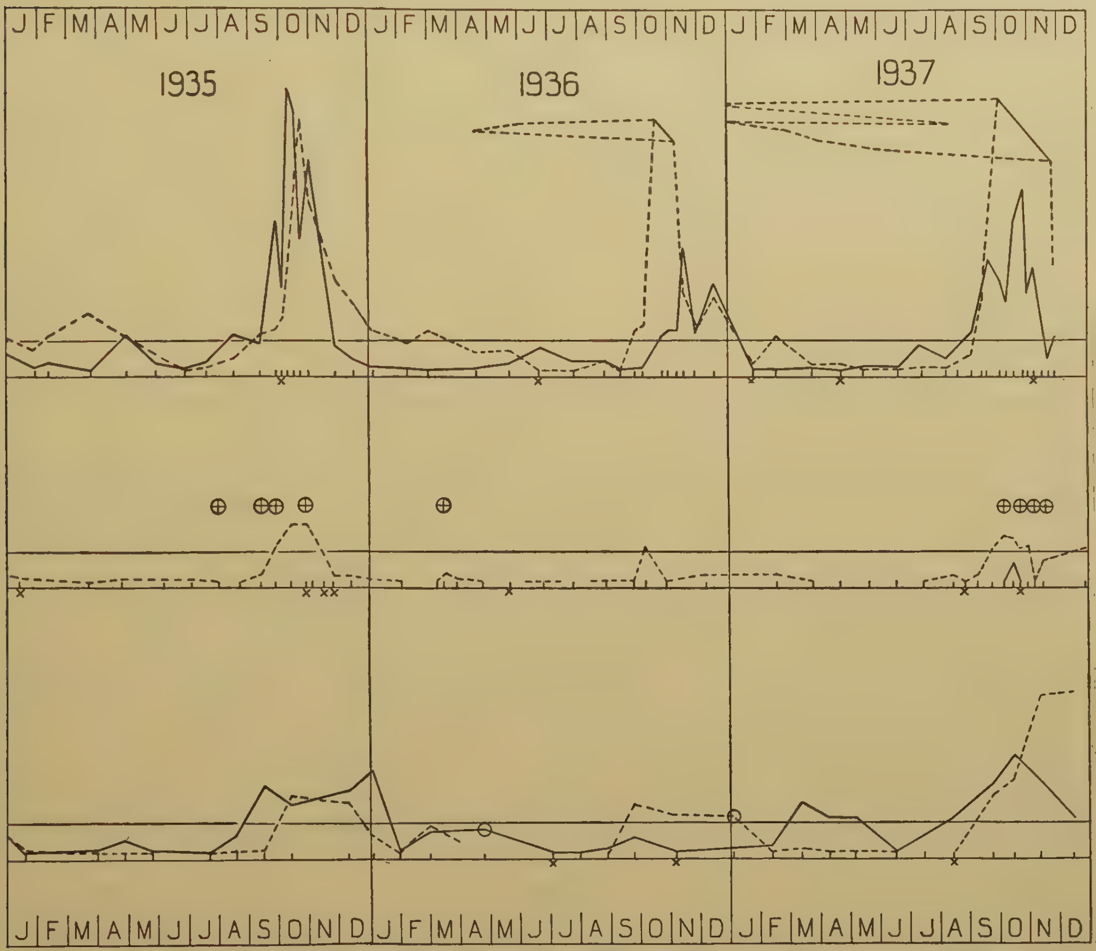
Text-fig. 4.—Similar to Text-fig. 3 but for the autumns of 1936 and 1937. Here the graphs are smoothed by the data being treated in blocks of 10 miles. The scale is the same as that for Text-fig. 3. No traces were found on the record of 13th September marked *. The additional vertical lines H and N represent the positions of the Humber and Norderney light vessels respectively.

followed by a more or less gradual disappearance, in 1934 and 1936 the trend was more irregular. The early patches of 1934 disappeared in October, others reappearing again in November, whilst in 1936 the maximum was much later than usual and further irregularities occurred. The latter year was also noteworthy in the appearance of the densest of the series of patches in December, a month which in other years has only produced small patches or traces.



TEXT-FIG. 5.—Graphs showing the fluctuations in the total numbers of *Rhizosolenia styliformis* (continuous line) and *Biddulphia sinensis* (broken line) recorded between June, 1932, and December, 1937. The records for the Bremen line (between Outer Dowsing and Borkum light vessels), the Rotterdam line (between E. Dudgeon and Maas light vessels) and the Copenhagen line (from Humber light vessel for 250 miles towards the Hanstholm) are shown separately. Above and below are time scales in months: J., F., M., A., etc. Each point on a graph represents the total number of cells of the particular diatom found on one record; the exact positions of each record in relation to the time scale is shown as a small vertical line against the base-line of the graphs. The scale of numbers is in

Text-fig. 5 shows the *total quantities* (see p. 91) found on each record during the period. The autumnal maximum is seen in each year and, as far as this material will permit, we may obtain an idea of the annual variation ; the quantities were the greatest in 1935, with 1937 similar but lower. We have already commented upon the scarcity of records in 1932–33, and the consequent risk of missing patches when they occur over the line ; the findings of Savage and Wimpenny (1936) would suggest that we may have missed the densest period in 1933 and possibly in 1932 also. But in assessing the relative quantities we may also consider the time and space extents of the productions, and there is reason to think that we have sufficient records in these and the later years to decide that the *duration* of significant patches



thousands of cells per record ; it should be noted that the vertical scale has been exaggerated below the 10,000 point in order to magnify the small but often significant changes which occur when these diatoms are scarcer. The true base-line, however, is also shown (i.e. just below point " 10 " on the scale). Records covering less than half the standard distance (see above) have been omitted unless where indicated as an open circle ; records covering less than 80 per cent. are indicated by an ×. The few traces of *R. styliformis* on the Rotterdam line are indicated by a + sign within a circle. (The high peaks in the *Biddulphia* graph for 1936 and 1937 are shown folded over to the left for space economy.)

over this line in 1932 and 1933 must have been much shorter than in the later years, and that any extensive occurrences did not exist for long.[1] This feature is clearly shown in the figures if we consider the extent of the autumn patches as they appear above the "true" base-line (see p. 92); the longer periods occurred in 1935 and 1937, whilst in addition we may note the unusually later production in 1936, with its rather smaller but still extensive patches.

Although occasionally no trace of it has been found, it has been seen in each of the twelve months, and only in February and April, 1937, in March of 1934 and 1935 and in June and July, 1932, has it not been recorded, although reference to the figures shows that occasionally a month has not been sampled. Sometimes cells were found in the Tank Residue which were not shown in Plates I and II.

Copenhagen Line.

All the records are shown in Plates III and IV, there rarely being more than one record in any month. As on the Bremen Line, there is a periodicity in numbers and variations between the different years. With the exception of a very dense patch in January, 1936, which we should associate with that of December, 1935, the period January–June is one of general scarcity; only in the spring of 1937 were more than isolated patches found. Autumnal patches occurred in October and November in 1932–34, and extended into December in 1934. In 1935 a small western patch in August was followed by large bimodal patches in September and October with smaller ones to the east. Although unfortunately we have no record for November, in December the diatom was still abundant, a large patch in the centre of the line suggesting a connection with that found in January, 1936. The records of 1936 were unfortunately few, the data for the western end of the line being particularly poor; only one small autumnal patch was found, in October. The most extensive quantities both in time and space were found in 1937, western patches appearing from July to December, together with varying quantities in the east and centre from September to December.

Text-fig. 5 shows the total quantities for this line, the autumnal maximum lasting the longest in 1935, although that of 1937 showed quantities nearly as great and generally more extensive. The only significant spring quantities were found in 1935–37, those of the last year being considerably the largest. In comparison with the Bremen Line we should note that the autumnal maxima here occurs later or persists until a later period in each year.

As on the Bremen Line, this diatom has been found in each of the twelve months, and, in fact, has only been absent in March, 1933 and 1934, June, 1932 and 1935, July, 1932 and 1933, August, 1932, and November, 1936.

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[1] On the other hand, although the quantities in 1932 and 1933 were estimated on a broader basis than in the later years, we know them to have been greater than in 1934 (although less extensive in time and space), and colour estimations make it certain that they were much below the maximal densities of 1935–37.

Rotterdam Line.

Such traces as have been found on this line are shown in Plate IX, where they appear as vertical strokes, within circles, in distinction from the traces of *B. sinensis*. Where these coincide in 1936 and 1937 the vertical strokes representing *B. sinensis* have also been included in the circles. Traces have been mainly limited to odd broken cells and over the six years have been mainly found in the autumn; such as are referable to position have been in the west and centre. Most of them occurred in 1935 and 1937, in which year there was a very small patch (black in Plate IX) on the western half of the line in October. No signs were found in 1933 and 1936.

Esbjerg Line.

This line was introduced in 1936 in order to extend and to confirm the evidence from the older lines in this region; the graphs for 1937 are shown in Plate X. In 1936 only a few records were obtained and the autumn records revealed no signs of this form; whilst alone these few records would not provide adequate evidence of its scarcity, we may consider them in conjunction with its absence on the Rotterdam Line and general lower numbers on the Bremen and Copenhagen Lines in that year. The graphs for 1937 suggest that *R. styliformis* was still rather scarce on the line, but traces were found in May and traces and small patches at the north-eastern end of the line in the autumn; this increase compared with the previous year at the same time is paralleled on the other lines.

Since the data for this line is incomplete, it seems more suitable to defer the production of figures for total quantities (such as have been prepared for other lines) until a later paper, when similar data for a further period will be available, Meanwhile, apart from these few remarks, the chief value of the additional line will lie in the greater detail and co-ordination available in those of the serial maps to which these records apply (Plates XXII to XXXVI); they will be discussed further in relation to these.

Distribution over the Area.

Plates XXII to XXXVI show the distribution over the whole area by means of representative records for each month on such lines as were sampled in that month. Further details regarding these maps are given on p. 90, and here it remains merely to point out that readers should refer to the graphs discussed in the previous pages for such of the records as we have, for reasons of economy, been compelled to omit from the serial maps. The vertical lines used as ordinates in the graphs of Plates I to XXI represent also the positions of the light-vessels used as the normal termini or reference points in the charts and represented on them by various letters (see legends). For reasons of economy and purposes of comparison we have combined two species on the set of charts, and *R. styliformis* is here represented by the blacked-in graph and small vertical strokes below the base-lines.

Consideration of the data provided by these charts will perhaps make it more evident why I have considered it suitable to review first the findings on all the records for any one line, and only later to relate these in such manner as seems suitable. Two reasons contribute to this : (1) It has not been possible (and rarely will be) to obtain all records for one month even within one week (here we have been bound by sailing schedules and by accidents due to weather conditions and mechanical breakdowns), and so the charts cannot be comparable in the way in which we can compare the graphs already discussed ; (2) having only data from discrete lines, the relations between them must be analysed with great care ; the introduction in 1936 of a line which crosses two others helps in this process of relating the whole, and in later years we shall be able to go further than this, but the evidence for co-ordination must necessarily remain to a large extent circumstantial.

It will be of value to consider this question of relationship at this stage, and we may refer to Plates XXXIII to XXXV for data. Here are patches of *R. styliformis* and *B. sinensis* on most of the records, and we can consider the relations between them. Frequent reference to the different lines will be necessary in the discussion, and the letters B, C, E and R will be used to indicate the Bremen, Copenhagen, Esbjerg and Rotterdam lines respectively. In September and October there are patches of Rhizosolenia at the western ends of B and C, and although we cannot have proof, there seems good reason to think that they are different cross-sections through one patch at the edge of the Dogger Bank ; this seems the more likely when we look at corresponding periods of other years and see (*e. g.* particularly in 1935) similar arrangements at the ends of the two lines, whilst the work of Savage and Hardy (1935) and Savage and Wimpenny (1936) has shown that such patches may occur frequently in such positions. Since this seems reasonably probable, it might be a working hypothesis that the smaller patches found in neighbouring places are also cross-sections through similar patches, but we must always bear in mind that there may be more than one patch in an area such as this, and at times there is good reason to believe so. The relationships between the patches of *B. sinensis* on B and R present similar problems, but even greater because of the greater distance between the lines in the region where *B. sinensis* is abundant on both ; in 1937 particularly, it would be difficult to suggest any definite association if it were not for the presence of records on the E line, which enables us the more definitely to believe that in August, for example, there was no appreciable concentration of Biddulphia between lats. 52° and 54° N., whilst in September there probably was a patch extending over the E and R lines, a much larger one round the junction of B and R, and one or more to the north of these. Even with such data, which is about as good as we are able to provide for this survey, we must realize that there are appreciable uninvestigated areas each month, *e. g.* that between B, R and E, in which a large patch might lie unsampled. This means that deductions cannot always be made with reasonable probability, but on the other hand, it is sometimes possible to deduce from the extra data in supplementary records (shown for this three months on Plate XXXV) the greater or lesser improbability that such further patches are in existence —the waters bearing patches are nearly always in movement, and the larger ones usually betray their presence by impinging on one or another line within the month.

This is a matter which must be discussed more fully when the phytoplankton and water movements are under consideration, but one cannot stress too strongly that the attempt to build up a two-dimensional picture from the strictly one-dimensional data available must be done with the greatest care when one species alone is under review, although in a review of the plankton as a whole the different ecological complexes will help to build up a more concrete picture.

At this stage it seems unnecessary to comment at length on the distribution as shown by these maps, which are expressly used so that they shall, as far as possible, speak for themselves and so avoid lengthy description. Details will be referred to in later sections, and future papers where particular points are concerned, though here we may review very briefly the general cycle as seen in the charts and draw attention to some matters of special interest. We may start for convenience in June, and from then to August we may note the appearance of traces and (usually later) patches generally towards the western end of B; in association (*i. e.* fairly close to B) there tend to be patches on C which are usually smaller. On the whole we may say the traces on B are a little more central in July than in June; in August they are rather more to the west again, and sometimes rather larger, but in 1935 and 1937 we may note also that the diatom has appeared in the region of the Heligoland Bight (also in July, 1934). With the exception of 1936, September shows an increase throughout, the bulk usually being in the west, with more or less extensive easterly components present in some years. Whilst the maximum is usually on B it may, as in 1935, be on C; in this month also we see the first traces on R.

In most years we find the maximum quantities in October,[1] but 1934 and 1936 are exceptions. The bulk of the production is in the west, but eastern growths are still evident, and in each year (except 1936) have by now appeared on C as well as on B. In 1935 and 1937 we should note that the main patches are bimodal, those for 1935 on B and C being suggestively similar. By the end of October the main or " primary " patch tends to be situated more towards the centre than in the early part of the month and in September. Again, with the exception of 1934 and 1936 there has been a reduction in numbers in November and a greater proportion of the total would appear to be typically on C; eastern traces on B are by now rarer. In 1934, however, there is a " return " of small patches (there being only traces in October), and in 1936 the first major growth is seen on B, only to decrease towards the end of the month and to appear denser still in

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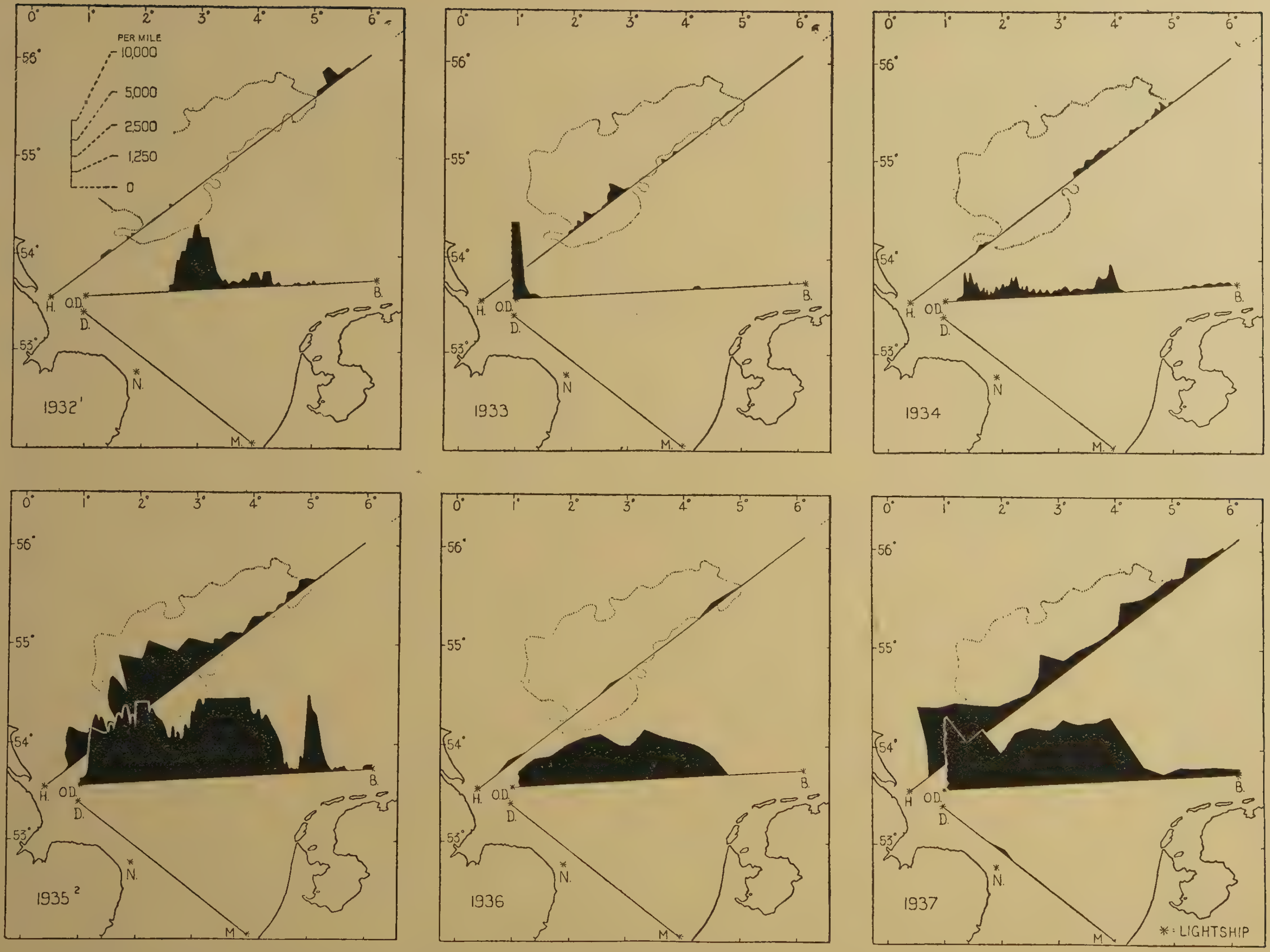
[1] The 1933 maximum according to us was found, in fact, on 27th September, but as we had another September record shortly before that, and there is no October record, this has been used as representative of October, and there is little doubt that the maximum was to be found in that month.

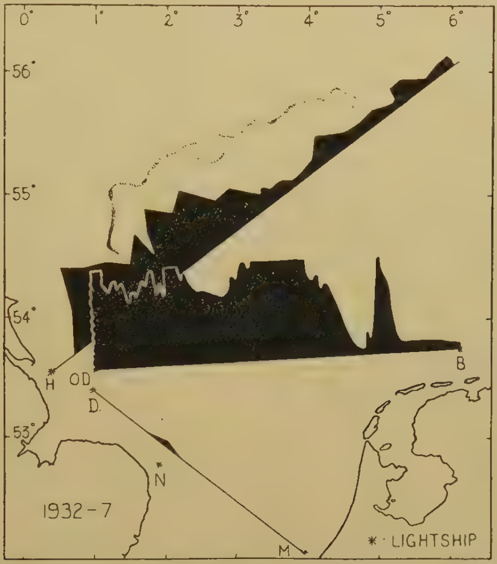

PER MILE
10,000
5,000
2,500
1,250
0
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
1932¹
1933
1934
1935²
1936
1937
✳: LIGHTSHIP

TEXT-FIG. 6.—Charts showing the maximal quantities of *Rhizolosenia styliformis* in numbers per mile (scale inset) recorded in each year at different points along the three lines.

[1] 1932 was incompletely sampled. [2] The data for January, 1936, have been included with those for 1935 (see text).

December; another December patch appeared on B in 1934, but there was a very marked reduction in all other years with the bulk of the form characteristically spread over C.

Typically from January to March there are only scattered traces on B and C, and for this reason the enormous patch on C in 1936 is the more striking (it provides the greatest density found on this line). There can be little doubt that this may strictly be considered as belonging to the previous autumn and winter development, and for this reason it has been included in the graph of maximal quantities for 1935 in order to prevent it from overweighting the maxima for 1936 on C (the actual date is 4th January). We may note also a dense patch on C in 1937. Such spring growth as is found usually occurs from April onwards and is scattered on B and C, small patches appearing in 1935–37 and disappearing by June.



Text-fig. 6a.—Chart showing the maximal quantities of *R. styliformis* in numbers per mile recorded over the period June, 1932–December, 1937, at different points along the three lines. The separate year charts in Text-fig. 6 are here combined.

Whilst the annual cycle of development shows essentially the same features each year, perhaps more striking are the differences which may occur. As pictured above, the general cycle is in broad agreement with and to some extent amplifies the findings which have been summarized by Ostenfeld (1931) from the early surveys of the International Council. One or two points, however, may be commented upon at this stage. The first concerns the almost permanent appearance of the form in this area compared with the general idea of its distribution in the past, since it has usually been considered to be a visitor in the North Sea, arriving under the influence of currents. It is true that Ostenfeld (*loc. cit.*) points out that such incursions may give rise to subsequent local flowerings, but it has, in fact, usually been treated as though it were truly oceanic, and this is not necessarily in accord with the great flowerings which may be found so far south in the North Sea, and even less with its persistence there. From 1932 to 1937 we have obtained samples in 67 months, and it has only been absent from the rolls in 4 of these ; in view of the very small samples taken by the recorder, this absence by no means proves that the form was ever entirely absent in the area. We can only come to the conclusion that, however much it may be under the *influence* of oceanic conditions, during this period at least, there must have been what we can only term an indigenous flora, and one persisting throughout very variable conditions of temperature and salinity. As far as they are available the results of Savage and Wimpenny (1936) for 1932 to 1934 show this also, whilst Savage and Hardy (1935) earlier suggested that the distribution for this form in 1924 gave ground " for believing that there are local flowerings " in this area. On the other hand it is not suggested that all the populations found have arisen in this area, and there may well have been a mixing of different " bodies " of the diatom from time to time.

Many of the variations from the general trend outlined above have been mentioned in discussing the data for the individual lines, but some others may more suitably be referred to here. Firstly, we may consider the evidence of the area as a whole regarding the quantities recorded. It seems probable that 1935 provided the greatest total bulk (*i. e.* allowing for extent of the patches in time and space), whilst 1937 was second. As far as these records go 1934 would appear to have provided the lowest maximal numbers, although the patches were more extensive then than in 1932 and 1933. Whilst 1936 ultimately provided fairly large numbers on B, the numbers on C, as far as the records go, were quite low. These findings are shown diagrammatically in Text-figs. 6 and 6*a*, where the maximal quantities over all the lines are shown year by year. From this it would appear that there have been considerable changes between the years, and these not always in one direction, but a little further consideration to other factors will suggest that this is capable of some qualification.

Whilst the usual process, characteristic of each year, has led to the production of autumn patches which are usually at first most dense over the western end of B, and later may be denser over the centre and east of C, and which greatly outweigh the slight spring flora which may appear, we may further summarize the years as follows :

1932 : Moderate numbers, mainly over the centre of B, and much lower ones over the eastern and western ends of C. General " movement "[1] north-easterly. Large numbers were evident on B only for a short time. The two records from 1931 suggested numbers to be even lower than in 1932.

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[1] " Movement " here denotes general change in position.

1933 : Records incomplete in the middle of a significant part of the cycle, but the numbers were at least as high and probably higher than in 1932. The largest numbers on C were found in the centre, although we cannot say that they were absent in the west and east. Change in position was generally towards the east and north. Persistence over B can have been for little more than one month.

1934 : Numbers definitely lower than in 1932 and 1933, but patches were much more extensive on B, and although they fluctuated they persisted for a much longer time. Lower numbers were over the east and west of C, and the general " movement " was north-easterly.

1935 (including the January record on C in 1936) : The highest densities were obtained here on B and C, whilst extent in time and space were on the whole similar to 1937 and much greater than in any other year. Greatest densities appeared over the western ends of B and C, and as the season developed there was an undoubted anti-clockwise " movement ".

1936 : Numbers lower on B and very low on C, no significant patches appearing until November, in contrast with the usually appreciable September patches in other years. The fluctuation on B is not dissimilar from the conditions in 1934. The bulk was found over the west and centre of B, and there was some movement in an easterly direction. Whilst small patches lasted from June to January, 1937, large patches were present only for a short time.

1937 : Densities approaching those of 1935 were attained, mainly over the western ends of B and C, although there were patches at their eastern ends. The only recorded patch on R was found. Large numbers were evident for a long period, and the general " movement " was undoubtedly towards the north and the east.

Two important points emerge from this summary. On the whole we should have to decide that there had been an increase in quantity from 1932 to 1935, although 1934 was in some respects peculiar. 1936 showed typically lower numbers during the maximal period of other years, whilst attaining moderate densities later on B, but 1937 showed some similarity to the general conditions of 1935 with rather lower densities. The second point concerns the north-easterly " movement " apparent in most years.

The significance of this general trend is discussed on p. 162 in relation to other forms found in this work and in other areas. From such results it should be possible over a long period to obtain a set of standards for comparison, and as a basis for general forecasting. The more detailed variations which have been found have their own more immediate value, and will be discussed from time to time in relation to other factors.

Text-figs. 6 and 6A showing the maximal quantities found over the lines bring out one or two other features. With rare exceptions we find that the patches at the western end of the Bremen Line tend to end abruptly in the neighbourhood of the Outer Dowsing Light-vessel ; the extensions of this line in 1937 have helped to delimit the edges of these patches more certainly, and there is reason to believe that this light-vessel forms a significant terminus, whilst there is some reason for considering the Borkum Light-vessel in the same manner. Similarly we can see that patches on C have never approached nearer than a point some 20 miles distant from the Humber Light-vessel, and that this was only obtained in 1935–37. These points, combined with the sparse occurrences on R, provide for the period a fairly distinct western boundary for productions of this diatom. Eastern limits are by no means precise, but clearly the greatest numbers are usually in the west.

Co-ordination between these results and those of other workers at the same time in the area—principally Savage and Wimpenny (1936) in 1933 and 1934—will be dealt with in detail in a later paper on the general survey in relation to hydrological conditions and movements in the area. We may state that, on the whole, comparison of these results with those of Savage and Hardy (1935) and Savage and Wimpenny (1936) shows no serious divergence, although there are certain discrepancies which must and, we believe, can be resolved. When the limitations of the two methods have been allowed for it is possible not only to see confirmation between the results, but also to see how the methods can be complementary one to the other in various ways.

One more point remains to be discussed. In this and similar sections dealing with the distribution and changes in numbers of the various species, it would be desirable to make some estimate of the rates of growth and general development of any form, since the present material provides the first survey over a large area within relatively short time intervals. The problem, however, is a complicated one. Reference to Text-fig. 5 will give a good idea of the total numbers found over the lines from time to time, but it will be clear that this is very different from the required estimate of growth and development for a number of reasons. We have to bear in mind the features peculiar to the recorder method : (1) Even in the case of a large form such as *R. styliformis*, the numbers are almost certainly less than those in the sampled water ; (2) we know that necessarily the recorder does not always pass through the densest areas of any patch ; and (3) we have yet to prove continuity from patch to patch between consecutive records and adjacent lines. Again, on more theoretical grounds, and as already explained on p. 88, results such as these, however they may be obtained, only give what may be termed the " residual population " at any time. Any increase or decrease found between consecutive surveys only shows the net change in number after some period in which death and loss have occurred due to a variety of reasons, perhaps feeding by herbivorous plankton being the most obvious. Whilst of some value, in that at any moment this estimate of the residual population more or less exactly forms a basis on which to speculate upon the future available source of production (*e. g.* the available food supply for some herbivore), it seems clear that until we know very much more regarding the life of any basic producer and that of its fellows in the community, the values of a series of "residual populations" may give a very limited idea of the sequence of production variations. Until we know that it is most unlikely, or even impossible, for the appropriate herbivores to affect seriously the stock of any diatom during its most productive stage, we can never avoid this criticism. At present we have no definite knowledge whatever regarding the relations between the "residual stock" and the actual production for any diatom. Our knowledge could not be appreciably improved by means of more intensive investigations, and for any mixed population contemporary analysis of the relevant chemical salts will not necessarily provide the information; nor yet the analysis of the numbers of dividing cells, since these analyses can have but momentary value, being dependent upon the immediate conditions of the environment. A number of factors are playing their parts in this matter, and for its elucidation we need to investigate some characteristic of the stock in which the effects of these factors are at a minimum. It seems possible that such a characteristic may be that of cell diameter, which has recently been investigated by Wimpenny (1936) from another point of view. This is not likely to be affected by the depredations of herbivores, and so long as we are able to take a random sample of the population, results from its measurements will not be so affected by the peculiar effects due to the collecting appliance (clogging and filtration problems). The possible effects of the physical and chemical environment should be reasonably easy to ascertain, and may not be extensive. Subject to these possible effects being shown to be inconsiderable *or adequately measurable*, it would seem that the gradual reduction in size of the diameter of the cells in any self-contained stock of diatoms may bear a relation to the number of divisions undergone by the majority of that stock; by the continuous measurement of this value we may be able to obtain a better conception of the varying rate of division and consequently of the "production" of the stock than by any other method yet attempted. Furthermore, as Wimpenny has pointed out, by means of these measurements we are able to ascertain more certainly the relationship of patches some distance apart in time or space. Garstang (1938), in his review of Wimpenny's analysis, criticizes the chief use to which the latter has applied his data, and in emphasizing their application to the problems of the life-history of patches, he points out also the peculiar suitability of the recorder material in this respect. Measurement of samples of phytoplankton collected during the earlier part of the survey has been in progress now for some time, and meanwhile measurements are being made of the contemporary material, bearing in mind the different uses to which they may be applied. The results already show that the growth cycle can only be followed (as was also implied by Garstang) by consideration of the whole area of the North Sea, and that even then we may not be able to trace all the inter-relations of the different "bodies" of diatoms.

THE DISTRIBUTION OF *Biddulphia sinensis* OSTENF.

The general arrangement of the graphs is similar to that adopted for Rhizosolenia, the broad annual cycles being shown in Plates V to X (the patches appearing as blacked-in graphs above the base-line and traces as small vertical strokes below that line), whilst the details of the autumn programmes on the Bremen Line are shown on an extended time scale in Text-figs. 3 and 4 in association with the records of *R. styliformis.* Since two organisms are shown in these last figures, it has been necessary to show the patches of *B. sinensis* as broken-line graphs above the line, and its traces as small horizontal strokes below the line. The general course of the description will be similar to that adopted for *R. styliformis.*

Bremen Line.

Again it is evident that in each year there has been a cycle of relatively small spring growth and a very much more extensive autumnal production (Pls. V and VI). In June and July it has been usual to find only traces, although a small patch appeared in July, 1937. August has shown small eastern patches in the last four years which are the forerunners of the larger ones typical of the autumn, although in the first two years these did not appear until September. The densest concentrations have usually been found in October, although the greatest extension has sometimes occurred in November. In general the December patches have been smaller, although quite significant in 1934–36. Although there is this general similarity, there has been a marked difference in the spatial arrangement; the small patches of 1932 were mainly eastern, those of 1933 more central and those of 1934–37 generally much more widespread, usually appearing first in the east, with rather later central patches extending more or less to the west (particularly in 1935 and 1937), and then in a more central position in December.

Before dealing with the winter and spring developments we should note the following points: (1) the progressive westerly extension of the diatom throughout the period until in 1937, when the greatest production both in quantity and extent was attained, the dense zones of the diatom came nearer than in any other year to the Outer Dowsing Light-vessel; and (2) the very widespread productions in 1935 and 1937.

The patches and traces found in January are probably most correctly to be associated with those of the previous Decembers; although usually thin, we may note the greater numbers in 1936. In February and March there have usually been more extensive traces, together with eastern patches, the outstanding example being that in March, 1935. In April and May again the numbers have been lower, but patches have been found in the east and rather more generally in the west. These various patches show definitely that there is what may be termed a spring growth on this line, but we should note that not always has this been distinctly separated from the preceding autumnal developments.

The diatom has been found in each of the twelve months on this line, although apparently absent in June of 1932 and 1935–37, and in July, 1934.

Text-fig. 5 shows the total quantities on this line and serves to underline the steady increase from 1932 to 1937 (it seems possible that we may extend this to include 1931, since the two autumnal records which we then obtained, whilst in some ways unsatisfactory, showed much lower values than at similar times in 1932). Whilst in each year the autumn numbers always have exceeded those for the spring, there is a suggestion that the large spring growth of 1935 may have exceeded autumnal ones of some other years, *e.g.* 1931–33, although we must remember, as with *R. styliformis*, that the smaller number of records in the autumn series for these years may well involve the loss of important evidence ; on the other hand, the time and space extensions tend to confirm the general low numbers in 1932 and 1933. In comparison with *R. styliformis* we may note that the present form tends to produce a maximum a little later in the autumn, and that this is seldom quite distinct from a smaller spring production which is usually rather early. On the whole it is rather more of a winter form, although it is scarce in the middle of the winter.

Copenhagen Line.

The distribution is shown in Plates VII and VIII. It will be most convenient to begin the description in September, for whilst there have been traces and very small patches in the first three months, from April to August inclusive there have been only a few traces found in 5 records out of 25. Again the autumn is the period of maximum numbers, and the annual cycles are broadly similar in leading up to the appearance of eastern patches towards the end of the year, but there are also interesting differences. In 1932 and 1933 patches do not appear until December, whereas from 1934–37 eastern patches were found as early as the end of September, and persisted until the end of the year, or even longer. Again, whereas in 1932 and 1934–36 the western limits of these patches were some 220 miles from the Humber Light-vessel, that in 1933 was only some 150 miles away. Similarly, whilst the first patch in 1937 was situated as usual, the western edge became progressively more westerly until in December it was only some 80 miles from the Humber Light-vessel, although other patches extended eastwards of this up to the Hanstholm. We may note also the traces and occasional very small patches near the Humber at this time in earlier years.

From the condition found in December of each year it seems logical to consider the numbers found in the east in the earlier months as being related to those of the previous autumns, this being most clearly shown in January both of 1936 and 1937, and perhaps reflected in the February and March records of 1934. The widespread traces at the end of February in 1936 are unusual.

The differences between the annual autumnal patches may be seen from another aspect in Text-fig. 5 and, with the possible exceptions of 1934 and 1936, we are led to conclude that there has not been a spring maximum over this line, the autumn development being the characteristic one each year. Owing to its density and extension in space this attained a maximum in 1937, the totals increasing more or less steadily each year, although 1936 provided lower densities whilst persisting longer than in the earlier years.

Rotterdam Line.

The distribution is shown in Plate IX, and we see that but for a small patch in March, 1933, the patches are almost entirely limited to the autumn, although traces have been found at other times and mainly in the east. The major productions each year have been found in October, decreasing in November according to our records, with usually little more than traces being found in December. We may note, however, September patches in 1935 and 1937, and a relatively strong December one in 1937. Only in 1933, 1935 and 1937 were any appreciable western growths found. Perhaps we should note the bimodal patches found in 1935, central patches being joined to eastern ones, and the less obvious signs of such an arrangement in 1933 and 1934. Only one record showed a patch in the autumn of 1936, and it may be significant that this was more central than easterly.

The total quantities are seen in Text-fig. 5 ; the importance of the autumn patches is underlined, as also the greater productions of 1935 and 1937, 1936 resembling 1934 to some extent and the earlier years being probably even lower. As on the Bremen Line there are some signs of a spring growth. Unfortunately, we were unable to obtain records in February and May of the earlier years, but these were sampled in 1936–37, the only traces appearing in February, 1937. No signs were found in March of 1934, 1935 or 1937, April, 1936–37, June and July, 1934, 1936 and 1937, and August, 1933, 1934, 1935 and 1937.[1]

Esbjerg Line.

This line was introduced in 1936 in order to extend the observations from the older lines ; the graphs for 1937 are shown in Plate X. In the first year only a few records were obtained, and the data seems only relevant in association with those of other lines. The more complete year, 1937, shows a fair development of *B. sinensis* in the autumn, and although the maxima were in the north-east, patches were to be found along the line down to its terminus near the Sunk Light-vessel. The graphs for 1936 show that patches may occur in January and February also, whilst that for October showed a particularly large patch near the Sunk Light-vessel. There may thus be a spring maximum on this line, but the bulk would appear to be found in the autumn as on the others.

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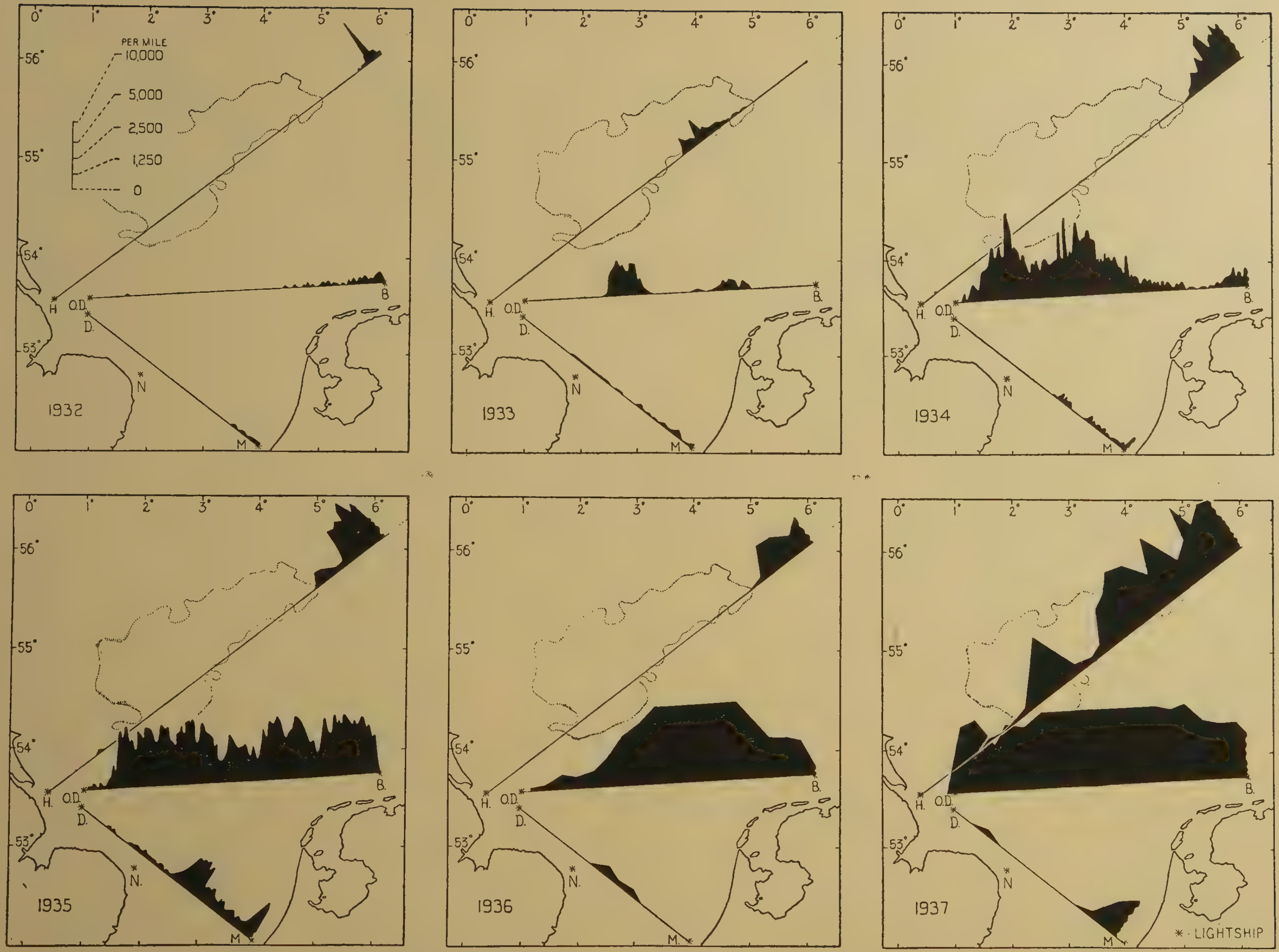
[1] In association with the results from this line, we may say that data from Plankton Indicator discs kindly taken for us by Prof. Gilson, showed appreciable numbers of *B. sinensis* over the eastern side of the Dover Straits in September, 1937.

Distribution over the Area.

The records are arranged in cartographical form in Plates XXII to XXXVI, along with those for *R. styliformis*, *B. sinensis* appearing as the broken line (patches) and its traces as horizontal strokes below the base-line. It is evident that we can trace a broadly similar annual cycle each year and the following features seem typical, although there are the usual variations ; we may, for convenience, begin the description in July when only a few (mainly eastern) traces have been found. There has usually been little further development in August, but the location of a large patch in 1937 on the new line renders it possible that there may in other years have been patches in the region of the Heligoland Bight; this tends to be supported by the appearance in September of typical patches over the eastern half of B (these were more towards the centre in 1933, 1934 and 1936). We note at this time also the first patches on C and R, the latter (in 1937) in close association with one found at the southern end of the new line. Maximal densities have usually been attained in October, and while patches are still evident in the east in some years, either they have extended centrally, or others have appeared to the west of the former on the Bremen and Rotterdam lines (examples are 1937 and 1935 respectively). The month of November has usually shown some decrease, although generally not so marked as in *R. styliformis* ; typically there has also been a further extension to the west on B, and in both October and November small patches and traces have been found at the western end of C in some years. The double patches seen in October are hardly perceptible in November. In every year December has shown evidence of a further decrease on the southern lines and typically the bulk has been found on C, some years providing an increase in that month or even the first patches then. On the whole there has also been a trend away from the western end of B.

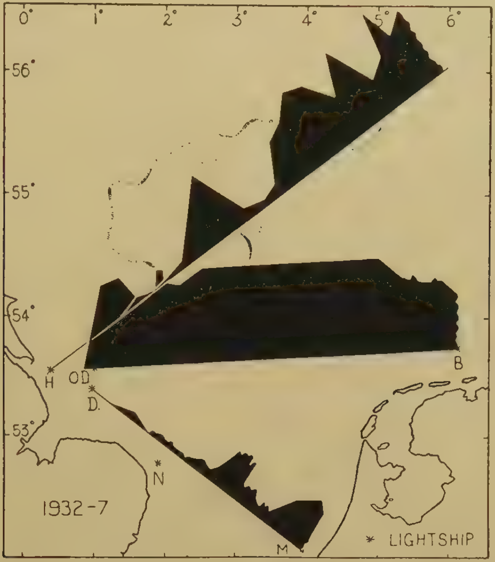
Such small patches and traces as have been found in January continue the conditions found in December, being situated a little more to the east in some cases, but evidently as residues of the former months. February and March have sometimes shown an increase, usually at the eastern ends of the lines (or in the centre of the Esbjerg Line); on the other hand, April, May and June have shown progressive decreases in numbers, and the main patches have been at the western end of B (see also Fig. 5).

The general distribution of this form and the contrasts shown between it and *R. styliformis* are in general conformation with the findings of the surveys organized by the International Council (Ostenfeld, 1931), although the great extensions towards the west in some years may be more recent features. Ostenfeld (1908) has described the earlier findings of Biddulphia in these waters, and the growth which took place between 1903, when it was first found, and 1907 ; records obtained since then (Savage and Hardy, 1935, and Savage and Wimpenny, 1936), whilst obtained at irregular intervals and apparently with no object of investigating this particular phenomenon, do suggest that in recent years it had increased, and the


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
PER MILE
10,000
5,000
2,500
1,250
0
H.
O.D.
D.
N.
M.
B.
1932
1933
1934
1935
1936
1937
✱ · LIGHTSHIP

TEXT-FIG. 7.—Charts showing the maximal quantities of *Biddulphia sinensis* in numbers per mile (scale inset) recorded in each year at different points along the three lines. Note that 1932 was incompletely sampled.

records we have available from 1931–37 suggest that the increase in density and the extension in space had not then stopped. This type of swing in the balance of the community will be discussed more fully at a later stage, but here it is interesting to note that the nearly related forms *B. regia*, *B. mobiliensis* and *B. granulata* (the first two of which used to be considered important in the area) have never in our records attained anything like the great densities of *B. sinensis*. It is interesting to note that the annual cycle as found by us is on the whole so similar to the course of events found by Ostenfeld : "it has found . . . places suited to it in certain areas from which every year in late autumn (September–November) it shoots up and spreads out with the currents" ; he quotes the Elbe, the Skagerrak and the Belgian coast as such places. We also found the spring maximum to originate in the same region, although the patches of the later spring months were over to the west.



Text-fig. 7a.—Chart showing the maximal quantities of *Biddulphia sinensis* in numbers per mile recorded over the period June, 1932–December, 1937, at different points along the three lines. The separate year charts in Text-fig. 7 are here combined.

Whilst considering the general distribution we may refer to Text-figs. 7 and 7*a*, showing the maxima throughout the period, and note the quite striking overall occurrence. We saw that with *R. styliformis* there was generally a marked discrepancy between the numbers found at the western ends of B and R, there rarely being even traces on R, although the numbers on nearby C were seldom so different from those on B. With *B. sinensis* we find that the discrepancy applies to both R and C, there seldom being any patches at the western ends of these lines, although neither is far from B where it was abundant ; whilst numbers may be large over the greater part of B, they are rarely found other than at the eastern ends of R and C. The conditions which can account for such a distribution and the variations which are found (*e. g.* on C in 1937) may well prove to be significant.

We have said that there are variations between the different years, and the most striking of these is probably the gradually increasing quantity found on the records from 1932 (or 1931 ?) to 1937, but the gradual increase is not shown on every line and we can best describe the individual years as follows :

1932 : Rather small eastern patches found first on B and R, and not until December on C. There is some easterly extension on B during the autumn.

1933 : In the autumn there were larger and more central patches on B followed by scattered patches on R, and one, in December, towards the centre on C. Such " movement " as was evident in the autumn was from centre to east on B. Small patches appeared on B and R in March.

1934 : Autumn patches first appeared on B, spreading from the centre nearly to the west, eastern patches appearing at the same time. The first significant patches on C and R were in October and in the east ; they lasted until December on C. After the extension towards the west there was a slight easterly " movement " at the end of the year. Small patches were on the east and west of B in the spring.

1935 : The autumn patches first appeared on B in the east and centre, with later ones spreading nearly to the west. A double patch was on R in October, whilst one in the east persisted on C from October to the end of the year, at which time an easterly trend was observed on B. The largest spring patches appeared this year in the east and west on B.

1936 : The first autumn growth appeared in the centre of B in September, later extending to the east and somewhat to the west, but less than in 1935. At the same time an eastern patch appeared on C and persisted after the end of the year (January, 1937), but as we have seen, only one small patch appeared on R. Although there is no evident easterly " movement " on B at the end of the year we should note the decrease in November and December. There was a fair patch towards the eastern end of B in January and February (on the Esbjerg Line).

1937 : The densest growths were found on B in the autumn of this year, first appearing in the east in August (*i. e.* on the Esbjerg Line) and then extending towards the centre of the line, and ultimately further to the west than previously had been attained. Large patches appeared on C in September and, unlike other years, they also extended to the west during the next three months, whilst on R the most westerly patch of the period was found, and eastern patches extended from September to December. There was some recession towards the east on B near the end of the year. There was apparently no spring production of any size.

There are a number of points in these differences which enable us to qualify the general statement of a trend over the period, and as with *R. styliformis*, we should rather regard it as a trend from 1932 (or 1931 ?) towards 1937, in which 1936 and to some extent 1934 show retrogressive or peculiar features. Amongst these are the less westerly extension on B in 1936 and the low numbers found on R, whilst others can be inferred from the summaries above and from the diagrams. This will be discussed further on p. 162 and in relation to other subjects.

As with the previous form, the general changes over the years 1931–34 agree broadly with those found by Savage and Hardy (1935) and Savage and Wimpenny (1936), and whilst there are certain discrepancies at first sight (in addition to those involved in the different methods), the more continuous records obtained by the recorder make it possible to resolve these to a large extent (see a later paper, in which these results will be assessed as a whole in relation to the hydrology and movements in the area).

Two other matters may be dealt with briefly here. As we have pointed out on p. 88, it would be desirable to have some better measure of the general annual growth than is provided by Text-fig. 5. For reasons discussed there this can only give a very approximate estimate of the changes in the "residual" population, and the picture may not be closely related to the actual growth and death-rates of any form. It seems possible that with certain qualifications the continuous measurement of cell sizes might provide for this form (as for many other diatoms) a more useful measure of the varying growth than has yet been obtained, and this work is being started.

The other matter concerns the almost persistent occurrence of this diatom in some parts of the area. Out of the 67 consecutive months in which the area was investigated (1932–37) Biddulphia has only been missed on 7 occasions (never in 1935, and three times in 1936), and the small samples which are obtained in any one place suggest strongly that it may still have been present on some of these. Such findings are not so surprising for *B. sinensis* as they were for *R. styliformis*, since the former, during the period from its first finding in these waters in 1903, appears so to have increased that it has become a truly indigenous form. On the other hand, few other diatoms have been found by us to be so persistent in our samples, and whilst some of them must necessarily be ruled out of comparison owing to their very small size (they may only be caught when very abundant), there are others having a sufficiently similar size to have approximately the same chance of being caught. These findings lend weight to the conclusion of Ostenfeld (1913), that whilst *R. styliformis* "is . . . the most important of all plankton diatoms", yet *B. sinensis* "has been one of the dominant forms of the plankton" in this area, although it is important to remember that both have been subjected to more intensive analysis than has been usual for other forms.

The Distribution of the Other Diatoms.

As already explained, the concentration in the early years of the survey upon the economically important diatoms *Rhizosolenia styliformis* and *Biddulphia sinensis* (together with the Dinoflagellates and Phaeocystis) led, in the limited time available, to a much more cursory treatment of the remaining diatoms. This material in consequence has its definite limitations, and cannot be treated in the same manner as the forms just mentioned. Nevertheless provided its limitations are fully realized and accepted, it is felt that it may profitably be used in presenting a picture of the main phytoplankton changes in the area over the period under review, and in addition will be useful as a basis for comparison with the more detailed phytoplankton work in the extended survey undertaken since 1938.

These limitations must be carefully stated. It has been found by checking that the method of analysis adopted in the early years led to some errors in enumeration and identification. These have been corrected, whenever possible[1]; elsewhere the material may have been discarded, or if used (as in some types of numerical error), it is only with qualifications regarding the validity. This means that the negative evidence on some occasions will be misleading; the omission of some material will have given a false impression of the absence or scarcity of a species. Further, in the more cursory treatment of the remaining diatoms, the determinations have in many cases been carried only to the genus, or in some cases two or more species have been treated together as a subgeneric group. The latter step has been taken in some instances where specific identification has been doubtful. Unfortunate as these points undoubtedly are, it is felt that the data, with these qualifications kept in mind, are of significance and worth recording.

The occurrence of the different diatoms has been summarized in the following way: The records have been subdivided into blocks each of about 20 miles' distance; in 1936 and 1937 these have been exactly 20 miles, but in the earlier years blocks of ten sections have been taken, and these will each represent a distance varying between 15 and 25 miles according to the varying ratio of 1·5 to 2·5 miles per section (the actual ratio for each record will be found in the Record List in 'Bulletin' No. 2). The quantities within these blocks have been averaged to provide values for diatoms per mile per block. These values are then assessed on a broad scale of "traces", "thin patches" and "major patches"; the second category is on an average some ten times the density of the first, and the third category ten (or more) times the second. There are reasons to believe that the addition of a

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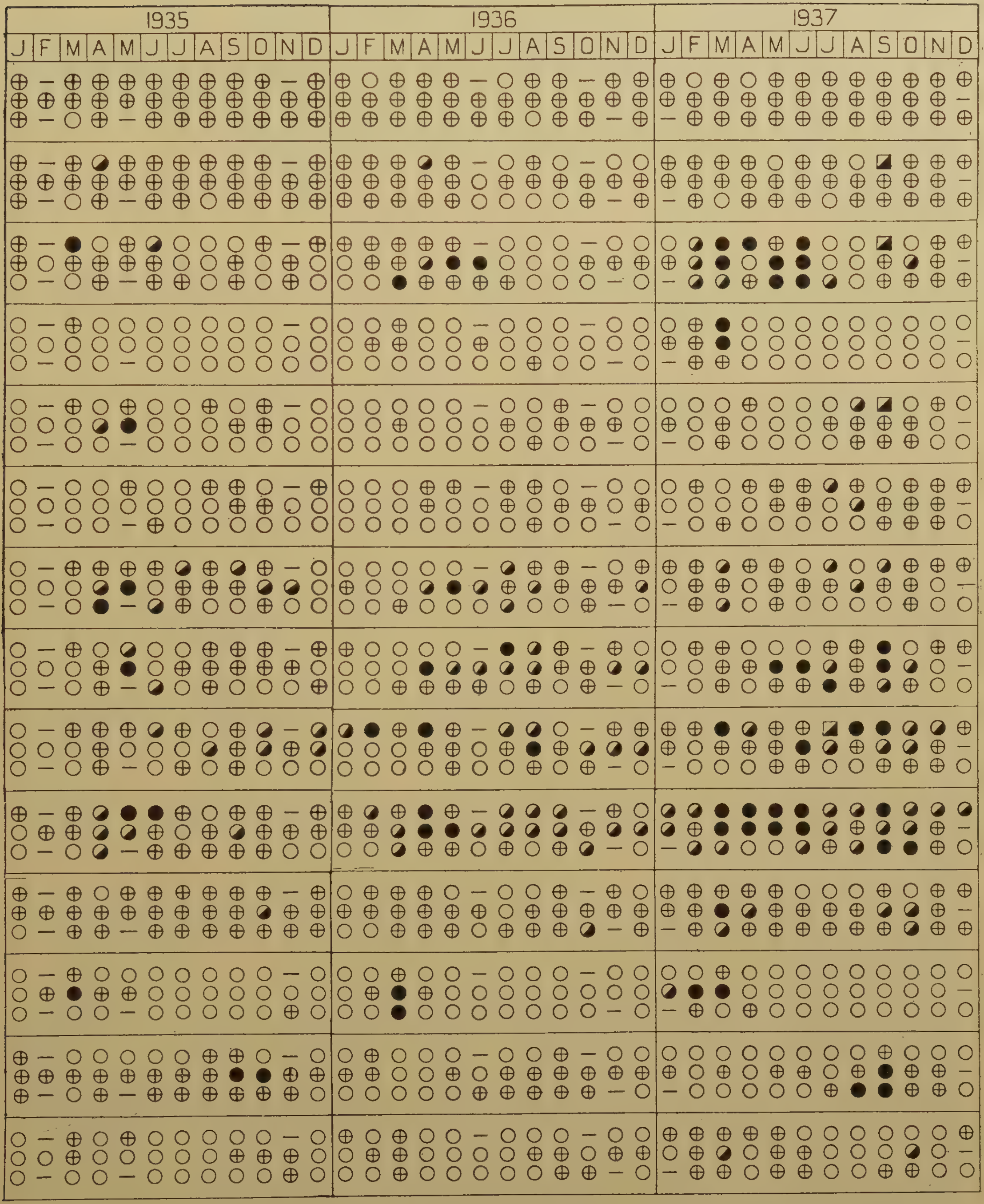
[1] We have been able to check certain of the errors. In 'Bulletin' No. 4 Mr. Rae will describe how, in at least one record for each route per month, an analysis has been made of every fifth or tenth tube for specific identification of the Copepoda, etc. At the same time the phytoplankton content of the tubes was analysed. From these estimates we obtain a random estimate of certain types of error, but whilst in many instances these can be detected, they cannot always be corrected. The tubes contain only the plankton which could be scraped off the silk, and so they usually contain only a part of the plankton which was originally caught. The chief types of error involved would appear to be (1) low estimations of some forms in the presence of others, and (2) mistakes of identity under the conditions of dense scum or in dense patches of diatoms.

TABLE IV.—*Showing the Periods of Occurrence of some of the Rarer Diatoms over each Line (C, B and R) during the Survey. The numbers 2–7 denote the years* (1932–1937) *in which they were found to occur during the different months.*

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Biddulphia rhombus	C	..	..	..	6	..	5	3, 7	5	6	7	..	..
	B	3, 5, 6	5	3–5	4	3, 4	4, 5, 7	4, 7	5, 7	2, 4, 5	2, 4, 5, 7	5–7	4
	R	..	7	..	5, 6	6, 7	5, 7	5, 7	4–7	5–7	3–7	5, 7	3
Cerataulina	C	6	7	5, 7	5, 7	7	4, 5	6, 7	7	5	5	..	4, 7
	B	..	6	6, 7	4, 6	..	..	..	..	..	5, 7	6	6
	R	..	7	7	..	..	..	..	7	..	6	7	..
Rhizosolenia fragillima	C	..	..	..	6	6	..	7	6	..	..	..	5, 7
	B	..	7	..	..	5	..	..	6	3, 4, 6	5, 6	5, 6	..
	R	..	7	6	5	7	..	..	..	7	7	..	..
Bacteriastrum	C	..	..	..	..	..	..	..	5, 7	7	7	..	..
	B	..	..	..	..	..	..	..	6	5–7	7	..	..
	R	..	..	..	..	6	..	6	7	7	6	..	..
Biddulphia alternans	C	..	..	..	..	..	..	..	..	7	7	7	..
	B	..	..	7	..	..	..	..	4	5, 7	5, 7	6, 7	..
	R	..	..	..	..	..	..	..	7	5–7	6, 7	..	..
Streptotheca	C	..	..	..	..	..	..	..	..	..	..	..	7
	B	..	..	6	..	..	..	..	..	7	7	6	..
	R	..	7	..	..	..	..	..	..	..	..	7	..
Hyalodiscus	C	..	..	..	..	..	..	..	..	..	7	7	7
	B	..	..	..	..	..	..	..	..	7	7	7	..
	R	..	..	..	..	..	..	..	7	..	6	..	..

DIATOMS	LINE	1932							1933												1934											
		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PARALIA SULCATA	C	○	○	○	○	—	○	○	○	○	○	—	—	○	⊕	—	⊕	⊕	⊕	⊕	○	⊕	⊕	⊕	—	○	○	○	⊕	○	⊕	⊕
	B	⊕	⊕	○	⊕	⊕	⊕	⊕	⊕	○	⊕	—	⊕	○	⊕	○	⊕	⊕	○	○	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	R	○	—	—	—	○	—	○	○	—	⊕	⊕	—	○	○	○	○	○	⊕	○	○	—	○	○	—	○	⊕	⊕	○	⊕	⊕	⊕
COSCINODISCUS SPP.	C	○	⊕	⊕	⊕	—	⊕	⊕	⊕	⊕	⊕	—	—	○	⊕	—	○	⊕	⊕	○	⊕	⊕	◐	◐	—	⊕	⊕	○	⊕	○	⊕	⊕
	B	⊕	○	⊕	○	⊕	⊕	⊕	⊕	◐	⊕	—	⊕	○	○	⊕	⊕	○	⊕	⊕	⊕	⊕	○	⊕	◐	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	R	⊕	—	—	—	⊕	—	⊕	⊕	—	⊕	⊕	—	○	○	○	⊕	⊕	⊕	⊕	○	—	○	○	—	○	⊕	⊕	⊕	⊕	⊕	⊕
THALASSIOSIRA SPP., ETC	C	○	○	○	⊕	—	○	○	○	○	⊕	—	—	○	○	—	○	○	⊕	◐	○	⊕	⦶	●	—	○	○	○	○	○	⊕	○
	B	○	○	○	⊕	○	⊕	○	◐	⊕	⊕	—	◐	○	⊕	○	⊕	○	⊕	○	○	○	⊕	⊕	●	◐	○	○	⊕	⊕	⊕	○
	R	○	—	—	—	○	—	○	○	—	○	⊕	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	⊕
SKELETONEMA COSTATUM	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	○	○	○	○	○	○	○	●	—	○	○	○	○	○	○	○
	B	○	○	○	○	○	⊕	○	○	○	○	—	⊕	○	○	○	⊕	○	○	○	○	○	⊕	⊕	⊕	⊕	○	○	○	○	○	○
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○
LEPTOCYLINDRUS DANICUS	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	⊕	○	○	○	○	○	○	○	—	○	○	○	○	○	⊕	○
	B	○	○	○	○	○	○	○	○	○	⊕	—	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○
GUINARDIA FLACCIDA	C	○	○	○	○	—	○	⊕	○	○	○	—	—	○	○	—	⊕	○	○	○	○	○	⊕	○	—	⊕	⊕	⊕	○	○	○	○
	B	○	○	○	○	⊕	○	⊕	○	○	○	—	⊕	○	○	○	○	○	○	○	○	○	⊕	⊕	○	⊕	○	⊕	⊕	○	○	○
	R	○	—	—	—	○	—	○	⊕	—	○	⊕	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○
RHIZOSOLENIA SHRUBSOLEI	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	○	○	○	○	○	○	○	⊕	—	○	○	○	○	○	⊕	⊕
	B	○	○	○	○	○	○	○	○	○	○	—	○	○	○	○	⊕	○	○	◐	○	○	⊕	○	⊕	○	○	○	○	○	⊕	○
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○
RHIZOSOLENIA STOLTERFOTHII	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	⊕	○	○	○	○	○	○	⊕	—	○	○	⊕	○	○	○	⊕
	B	○	○	○	○	○	○	○	○	○	○	—	○	○	○	○	○	○	⊕	○	○	○	⊕	○	◐	⊕	○	○	⊕	○	⊕	⊕
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	○	○	⊕	⊕	○	—	○	○	—	○	○	○	○	○	○	○
RHIZOSOLENIA ALATA AND RH. HEBETATA	C	○	○	◐	○	—	○	○	○	○	⊕	—	—	○	○	—	○	○	○	⊕	○	○	○	⊕	—	○	○	⊕	⊕	○	●	◐
	B	○	○	○	○	⊕	◐	○	⊕	○	○	—	●	○	⊕	○	⊕	○	(?)	○	○	⊕	⊕	⊕	●	●	⊕	◐	⊕	⊕	⊕	⊕
	R	○	—	—	—	⊕	—	○	○	—	○	⊕	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○
CHAETOCEROS SPP.	C	⊕	○	○	○	—	⊕	⊕	⊕	⊕	⊕	—	—	○	⊕	—	⊕	⊕	⊕	⊕	⊕	⊕	⊕	●	—	⊕	○	○	⊕	◐	⊕	⊕
	B	○	○	⊕	⊕	○	⊕	⊕	⊕	⊕	○	—	●	○	○	○	⊕	○	⊕	○	⊕	○	◐	⊕	●	⊕	○	⊕	⊕	○	○	○
	R	○	—	—	—	○	—	○	⊕	—	⊕	○	—	○	○	○	○	⊕	⊕	○	○	—	○	○	—	○	⊕	⊕	○	⊕	○	○
BIDDULPHIA REGIA ETC	C	○	⊕	○	○	—	⊕	⊕	⊕	○	○	—	—	○	⊕	—	⊕	○	○	⊕	○	⊕	○	⊕	—	○	○	○	⊕	○	⊕	⊕
	B	○	○	○	⊕	⊕	⊕	⊕	⊕	⊕	◐	—	⊕	○	○	⊕	⊕	○	⊕	○	○	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	○
	R	○	—	—	—	⊕	—	⊕	—	—	●	◐	—	○	○	○	○	⊕	⊕	○	○	—	○	○	—	○	○	○	⊕	⊕	⊕	○
BIDDULPHIA AURITA	C	○	○	○	○	—	○	○	○	○	⊕	—	—	○	○	—	○	○	○	◐	○	⊕	○	○	—	○	○	○	○	○	○	○
	B	○	○	⊕	○	○	○	⊕	⊕	⊕	●	—	⊕	○	○	○	○	○	○	○	○	⊕	⊕	○	⊕	○	○	○	○	○	○	○
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	⊕	⊕	○	○	○	—	○	○	—	○	○	○	○	○	○	○
BELLAROCHIA MALLEUS	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	⊕	—	⊕	—	⊕	○	○	○	—	○	○	○	○	○	○	⊕
	B	⊕	⊕	⊕	⊕	○	⊕	○	⊕	○	⊕	—	⊕	⊕	⊕	⊕	●	⊕	⊕	⊕	⊕	○	⊕	⊕	⊕	⊕	⊕	⊕	●	⊕	⊕	⊕
	R	○	—	—	—	⊕	—	⊕	○	—	○	○	—	○	⊕	○	⊕	⊕	⊕	⊕	⊕	—	○	○	—	○	○	⊕	⊕	⊕	⊕	⊕
DITYLIUM BRIGHTWELLI	C	○	○	○	○	—	○	○	○	○	○	—	—	○	○	—	○	○	⊕	○	○	⊕	○	⊕	—	○	○	○	○	○	○	⊕
	B	○	○	○	○	○	○	⊕	○	○	⊕	—	○	○	○	○	○	○	○	○	○	○	○	⊕	○	⊕	○	○	⊕	○	⊕	○
	R	○	—	—	—	○	—	○	○	—	○	○	—	○	○	○	○	○	○	○	○	—	○	○	—	○	○	○	○	○	○	○

TEXT-FIG. 8.—Diagrammatic tables showing the varying densities attained by the more important diatoms other than *Rhizosolenia styliformis* and *Biddulphia sinensis* in the three lines C, B and R (Copenhagen, Bremen and Rotterdam) month by month from June, 1932, to December, 1937. The months are indicated by the letters J., F., M., etc. One observation is given for each month in which a record was taken : ○ = none found, ⊕ = presence, ◐ = medium patch, ◪ = medium patch



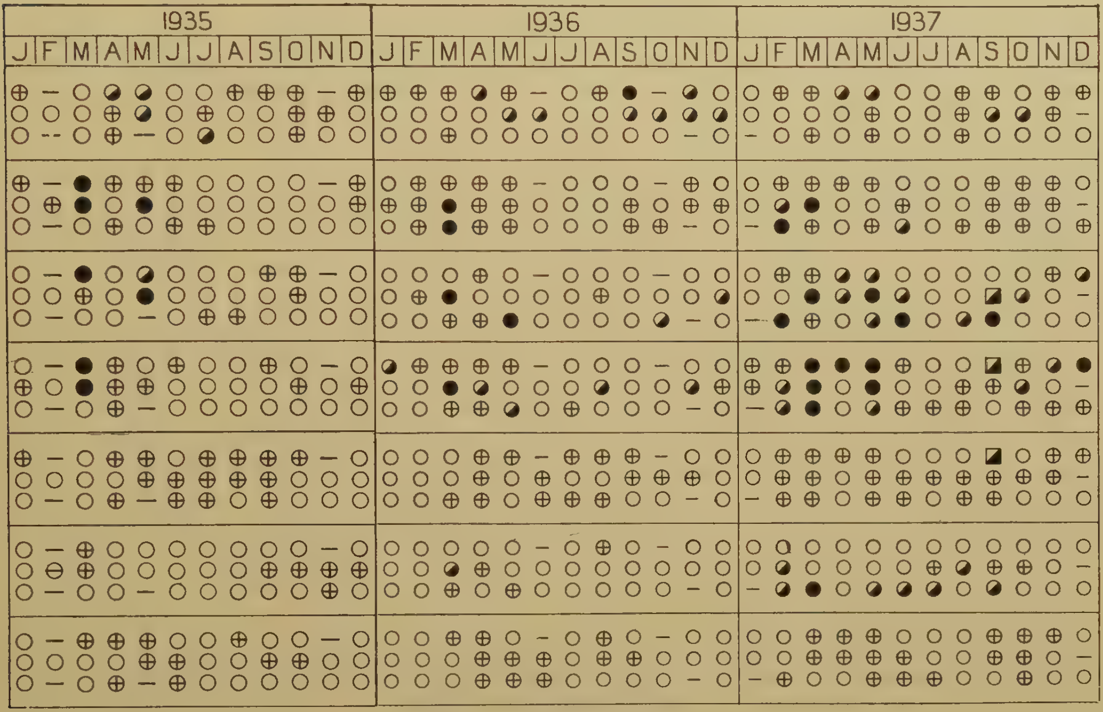
in the extended part of the C line, ● = major patch, and – = no record taken. Reference to the serial maps in Plates XXXVII to XLIV will indicate both the extent of the patches and which lines were not fully sampled in any month. For further explanation see text. The table is further continued in Text-fig. 8A overleaf.

further "very dense" grade would have been desirable, but certain aspects of the earlier work make it impossible to provide comparative data for such a grade. The third density may be taken to indicate all the most important patches, but those of intermediate value need to be variously assessed accordingly to the size, etc., of the cells concerned, although for all the larger forms these also should indicate significant patches. The "traces" have only their limited value as indications.

DIATOMS	LINE	1932							1933												1934											
		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
EUCAMPIA ZOODIACUS	C	○	○	○	○	–	○	○	○	○	○	–	–	○	○	–	○	⊕	○	⊕	○	○	⊕	○	–	○	○	○	○	○	○	○
	B	○	○	○	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○	○	⊕	○	○	⊕	⊕	○	○	○	○	○	⊕	○
	R	○	–	–	–	⊕	–	○	○	–	○	○	–	○	○	○	○	○	○	○	○	–	○	○	–	○	○	○	○	○	○	○
NAVICULA SPP. ETC.	C	○	⊕	○	⊕	–	⊕	⊕	⊕	⊕	○	–	–	○	⊕	–	○	○	○	●	○	⊕	⊕	○	–	○	○	○	○	○	○	⊕
	B	⊕	⊕	⊕	○	○	⊕	○	⊕	⊕	⊕	–	⊕	○	⊕	⊕	⊕	○	⊕	⊕	⊕	⊕	⊕	○	⊕	⊕	⊕	⊕	⊕	⊕	⊕	○
	R	○	–	–	–	○	–	○	○	–	⊕	○	–	○	○	○	○	⊕	⊕	○	○	–	○	○	–	○	○	○	○	○	○	○
ASTERIONELLA JAPONICA	C	○	○	○	○	–	○	○	○	○	○	–	–	○	○	–	○	○	⊕	◐	○	⊕	○	●	–	○	○	○	○	○	○	○
	B	○	○	○	○	○	○	○	⊕	⊕	⊕	–	○	○	○	○	○	○	⊕	⊕	○	⊕	○	○	○	⊕	○	○	○	○	○	○
	R	○	–	–	–	○	–	○	○	–	○	○	–	○	○	○	○	○	○	○	○	–	○	○	–	○	○	○	⊕	○	○	○
THALASSIOTHRIX NITSCHIOIDES	C	○	○	○	○	–	○	○	○	○	○	–	–	○	○	–	⊕	⊕	⊕	⊕	⊕	⊕	◐	●	–	○	○	○	○	○	◐	◐
	B	○	○	○	○	○	○	○	⊕	⊕	⊕	–	⊕	○	○	○	○	○	⊕	⊕	○	⊕	○	⊕	●	⊕	○	⊕	⊕	⊕	⊕	⊕
	R	○	–	–	–	○	–	○	○	–	○	⊖	–	○	○	○	○	⊕	○	○	○	–	○	○	–	○	○	○	○	◐	◐	⊕
GYROSIGMA SPP.	C	○	○	○	○	–	○	○	○	○	○	–	–	○	⊕	–	⊕	○	○	○	○	○	○	○	–	⊕	○	○	⊕	○	○	○
	B	⊕	○	○	○	⊕	○	○	⊕	○	⊕	–	○	○	○	○	⊕	○	○	○	○	⊕	○	○	○	⊕	○	○	○	○	○	○
	R	○	–	–	–	○	–	○	○	–	○	○	–	○	○	○	○	○	○	○	○	–	○	○	–	○	○	○	○	○	⊕	○
BACILLARIA PARADOXA	C	○	○	⊕	○	–	○	○	○	○	○	–	–	○	○	–	○	○	○	○	○	○	○	○	–	○	○	○	○	○	○	○
	B	○	○	○	○	○	○	○	○	○	○	–	⊕	○	○	○	○	○	○	○	○	⊕	⊕	○	⊕	⊕	○	○	○	○	⊕	○
	R	○	–	–	–	○	–	○	○	–	○	○	–	○	○	○	○	○	○	○	○	○	○	○	–	○	○	○	○	○	⊕	○
NITZSCHIA SPP.	C	○	○	○	⊕	–	○	○	⊕	○	○	–	–	○	○	–	○	○	○	⊕	○	○	○	⊕	–	⊕	○	○	○	○	○	○
	B	⊕	○	○	○	○	⊕	○	⊕	○	○	–	⊕	○	○	○	○	○	○	○	○	○	○	○	⊕	⊕	○	○	○	○	⊕	○
	R	⊕	–	–	–	○	–	○	○	–	○	⊕	–	⊕	○	○	○	○	○	○	○	–	○	○	–	○	○	○	○	○	○	○

TEXT-FIG. 8A.—Continuation of Text-fig. 8.

Text-figs. 8 and 9 provide a graphical representation of the variations in the occurrence of the more important species during this survey; the presence or absence of patches of the different grades, as revealed by these records, is shown month by month on each line. Some of the scarcer forms appear in Table IV in an abbreviated manner. In view of the extent of the material it is impossible to show all the occurrences of each form, and description will be limited to a series of short notes outlining the general distribution during the survey, variations and unusual features, and occasional comparisons with the findings of the International Council within this area. Graphical representation of the spatial distribution will be limited to a series of charts, Plates XXXVII–XLIV, showing the main phytoplankton complexes which have been recorded during the survey; except for one or two forms these will show the major and intermediate patches mentioned above for each species. These charts are more diagrammatic than the others of this kind, and certain slight differences in arrangement are due to this as are slight differences between these maps and Text-figs. 8 and 9. No extensions outside the original area have been used. From the charts it should be possible to see the main trend of events, and its variations, for each form, and to follow the distributions of different species in relation to those of others. In order to follow the whole phytoplankton cycle they should be considered in conjunction with the charts of Rhizosolenia, etc.



TEXT-FIG. 8A continued.

A striking feature of the results of this phytoplankton survey over the period under review is the tendency for a greater number of species to figure more prominently as the survey progressed, and even to attain their maxima during the last year. We were much disturbed as to whether this result could be due to an improvement in our technique as the survey progressed, and not to an actual change in nature. There is no doubt that our methods and our knowledge of the material have improved, but whilst this may to some extent have contributed to this effect, we have evidence that this has not been a major factor in the problem. This tendency was becoming very evident in 1935, and in order to obtain some check on it we examined the numbers of different forms present in the "tube analyses" (p. 75), and whilst we know that these are necessarily minimal, we found that generally the forms appeared in those tubes in the same order and in proportions similar to those which had already been found from analysis on the rolls. Whilst these last had been spread over a number of years and had been made by a number of workers, the tube analyses have been done within a short time, in chance order and all by the same person (Mr. K. M. Rae). This alone suggested that the changes were really significant. Again, the doubts were applied only to some forms which were small or easily damaged in storage, but we still found that some others to which these doubts were not applicable had also increased (*cf.* also the much more striking increases of *C. fusus* on the Rotterdam Line over this period, and the evident increases of *R. styliformis* and *B. sinensis*). Moreover, certain forms had either decreased during the period or had shown irregular variations and, in view of the whole series of factors, we have been led to conclude that whilst there may well have been improvements in the technique (particularly that involved in the decreasing time-lag between recording and analysis) which have led to relatively higher values in later years, yet the results show changes which have significance, the precise values not being obtainable (as, indeed, applies to other estimates based upon filtration, p. 77). A discussion of the significance of this increase in the phytoplankton during the course of the survey is reserved for consideration in the more general conclusions and will be found on p. 162.[1]

Brief notes will now be given regarding all the more important forms encountered, and these will include an indication of the tendencies of the different species to occur in association with other forms or to live in relatively " pure " communities. The recorder method provides useful material for such ecological correlations and the subject will be more fully dealt with in a later paper. The general identification and classification has been based on Lebour (1930).

Paralia sulcata (Ehr.).

This has been very widespread in time and space, being found in each of the twelve months, although seldom plentiful: the largest numbers were found in the autumn. As a whole it has had a very coastal distribution, rarely being found in the central parts of the lines, but as might be expected, being commonest in the presence of patches of debris, which are abundant at times in the waters of the southern North Sea. It has definitely been most common on line B, and rarest on C. Since this is a chain form and seldom more than a few chains are seen, only its presence has been considered as evidence, and no patches are dealt with.

Coscinodiscus spp. (C in Plates XXXVII–XLIV.)

As a whole the genus has been found in each of the twelve months, except in 1933 and 1936 when it was entirely missing in June. Patches (except one on the extension of the C line in September, 1937) have always been found in the spring, and have been dominantly *C. concinnus*. They occurred on line B in 1933 and 1934 and on C in 1934–36, mainly in the east and centre.

This is one of the few genera not having a maximum in 1937, and with the exception of the patch to the east of the usual terminus on C in September (not *C. concinnus*) there were no patches this year. It rarely attained great numbers.

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[1] Further evidence that this increase was an actual one in nature, and not entirely due to an improvement in technique, appears in the results for 1938–39 when a marked decrease was observed in many forms: see the addendum note on p. 168.

Thalassiosira spp. etc. (TH in Plates XXXVII–XLIV.)

Owing to the difficulty of identification on the roll when large numbers are present, we have found it better to combine the Thalassiosira spp. with Coscinosira spp. and Lauderia spp. In this area the dominant one has been *Thalassiosira* (*Th. Nordenskioldii* and *gravida*). Whilst very common at times they have never been recorded in August, being most abundant on lines B and C in the spring. Patches have occurred on all parts of the lines, but there are irregularities, *e. g.* on R, where no appreciable numbers were found until 1936 (east), whilst in 1937 they extended up to the East Dudgeon Light-vessel. On C we may note the unusually extensive patches in 1935 and 1937 (March), and on B in March, 1937. No patches were found on line C in 1936 or on B in 1935, and as a whole they were by far the commonest on all lines in 1937, in association with Chaetoceros spp., *Thalassiothrix nitzschioides*, *Asterionella japonica* and others in various combinations.

Skeletonema costatum Greville. (S in Plates XXXVII–XLIV.)

Since this form may not be found in representative numbers owing to its small size, and probably only the major patches are strictly comparable, we have limited consideration to these. It has rarely been seen from July to December, and only in 1936 and 1937 has it appeared on line R. The only patches appeared in April, 1934, on C, and March, 1937, on C and B; all were at the western ends of these lines. Its common associates have been Chaetoceros spp., Thalassiosira spp. etc., *Thalassiothrix nitzschioides* and *Asterionella japonica.*

The absence of an autumn secondary maximum may be of interest in view of the suggestion of Ostenfeld (1913) that this usually occurred in his data.

Leptocylindrus danicus Cleve. (L in Plates XXXVII–XLIV.)

This has been absent in February, June and December, and rare in January; it did not appear on line R until 1936–37. The greatest numbers were found in 1935 (particularly on B in April and May), but patches also occurred on C and B in 1937. In addition to *L. danicus* some very small cells were included which were probably *L. minimus* Gran.

Guinardia flaccida Castr. (G in Plates XXXVII–XLIV.)

The only patches were found in 1937 at either end of line C in July and at the western end of B; it has been very rare on line R. This is another form which is rather easily damaged and may have been missed on occasion, as some of the analyses of "tank residues" have suggested. A tendency to live in somewhat deeper waters than other forms may cause it to be rarer in our records than might be expected. It has been found throughout the year, but only once in February.

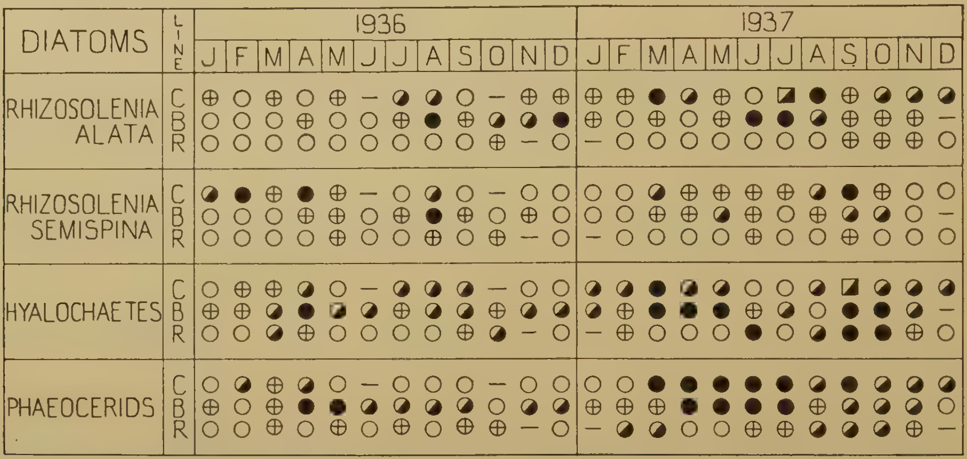
Bacteriastrum spp. (BTM in Plates XXXVII–XLIV.)

Although it would be impossible to vouch for all specific identifications in view of the peculiar difficulties of this work, the periodical confirmation and peculiar distribution of these diatoms make it reasonably certain that *B. hyalinum* Lauder (of Lebour, p. 83) is the one concerned; no certain specimens of *B. delicatulum* Cleve have been seen. Patches have been limited to the period 1935–37, occurring in August, September and October at the eastern ends of lines B and R; in addition one was found on R in May, 1936, and another outside the usual area (*i. e.* the extension of C) in September, 1937. It is probable that these, along with some associated forms, may form useful indicators of hydrological conditions in the southern area, and we may note that it was remarkably scarce in the early years.

Rhizosolenia alata Brightw. and *R. hebetata semispina* (Hensen). (R in Plates XXXVII–XLIV.)

It has been considered necessary to combine these forms to avoid the use of possibly erroneous data due to some confusion in the earlier years, and from time to time in very dense numbers of a mixed population. It seems probable that rarely, if ever, have cells of *R. hebetata hiemalis* Gran been seen in these records. The two species (*R. alata* and *R. h. semispina*) have been broadly separable in 1936–37.

As a whole they have been rare on line R (no patches), most of the patches being found in the spring and autumn on B and C, the greater number in 1936 and 1937 ; on the whole they have been rather more autumnal on B than C. As might be imagined, this heterogeneous group has had a widespread distribution, tending on the whole to appear over the central area of C and to be spread over B. The more detailed results for 1936 and 1937 show that *R. h. semispina*, although appearing in the autumn, was more typically a spring form (particularly in 1936), whilst *R. alata* was commonest in the late summer and the autumn. This is also borne out by the less reliable information for the earlier years (particularly on C), and is in general agreement with the findings of other workers (*cf.* Ostenfeld, 1913). Whilst forming " pure " communities of one or the other form (usually one is considerably dominant, even if they are present together), they have also often been found mixed with large numbers of Chaetocerids, and Thalassiosira.



DIATOMS	LINE	1936												1937											
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
RHIZOSOLENIA ALATA	C	⊕	○	⊕	○	⊕	—	◑	◑	○	—	⊕	⊕	⊕	⊕	●	◑	⊕	○	◪	●	⊕	◑	◑	◑
	B	○	○	○	⊕	○	○	⊕	●	⊕	◑	◑	●	⊕	○	⊕	○	⊕	●	●	◑	⊕	⊕	⊕	—
	R	○	○	○	○	○	○	○	○	○	⊕	—	○	—	○	○	○	○	○	○	○	⊕	⊕	⊕	○
RHIZOSOLENIA SEMISPINA	C	◑	●	⊕	●	⊕	—	○	◑	○	—	○	○	○	○	◑	⊕	⊕	⊕	⊕	◑	●	⊕	○	○
	B	○	○	○	⊕	⊕	○	⊕	●	⊕	○	⊕	○	○	○	⊕	⊕	◑	⊕	○	⊕	◑	◑	○	—
	R	○	○	○	○	⊕	○	○	⊕	○	⊕	—	○	—	○	○	○	○	⊕	○	○	⊕	○	○	○
HYALOCHAETES	C	○	⊕	⊕	◑	○	—	◑	◑	◑	—	○	○	◑	◑	●	◑	◑	○	○	◑	◪	◑	◑	◑
	B	⊕	⊕	◑	●	◑	◑	⊕	◑	◑	⊕	◑	◑	◑	⊕	●	●	●	⊕	◑	○	●	●	◑	—
	R	○	○	◑	⊕	○	○	○	○	⊕	◑	—	○	—	⊕	○	○	○	●	○	◑	●	●	⊕	○
PHAEOCERIDS	C	○	◑	⊕	◑	○	—	○	○	○	—	○	○	○	○	●	●	●	●	●	◑	●	◑	◑	◑
	B	⊕	○	⊕	●	●	◑	◑	◑	◑	○	◑	◑	⊕	⊕	⊕	●	●	●	●	⊕	◑	◑	◑	○
	R	○	○	⊕	○	⊕	○	⊕	○	⊕	⊕	—	○	—	◑	◑	○	○	⊕	⊕	◑	◑	◑	⊕	—

Text-fig. 9.—Arrangement similar to Text-figs. 8 and 8a but for *Rhizosolenia alata* and *R. h. semispina*, the Hyalochaetes and the Phaeocerids for the years 1936 and 1937. For explanation see legend to Text-fig. 8.

A note regarding *R. alata* may be added. Both the forma *gracillima* and the forma *typica* have been common in these records. The forma *indica* has generally been very scarce, but was unusually abundant at the eastern end of line C in the autumn of 1937.

R. Stolterfothii H. Pérag. (RT in Plates XXXVII–XLIV.)

Whilst occasionally a significant patch may have been missed in the earlier years, this form being among the more difficult to deal with after some period of preservation on the rolls, there can hardly be any doubt that it was most abundant in 1936, and that 1937 was probably next to that year in abundance. It has been found only once in February, patches being most common in the early summer and sometimes in the autumn. They were found on line R in 1935 and 1937 only, the greatest numbers appearing on B from 1934 onwards, and on C from 1935 onwards. Patches were found at the western ends of C and B, and at the eastern end of B and R, *i. e.* a typical coastal distribution. They have not generally been mixed with large numbers of other forms.

R. Shrubsolei Cleve. (RB in Plates XXXVII–XLIV.)

It has appeared in all months, although not in February until 1937. With the exception of one on line B in December, 1933, there were no significant patches until 1935, after which they mainly appeared in the spring, early summer and the autumn. It has been most common on B (particularly in 1936), but was also abundant on R in 1935 and on C in 1935 and 1937. The patches have been mainly spread over the B line, the centre and western third of C and the eastern end of R. On the whole it has tended to be most abundant when other forms were scarcer.

Other species of Rhizosolenia.

R. fragillima Bergen, *R. delicatula* Cleve, *R. Faeröense* Ostenf. and *R. setigera* Brightw. have all been found from time to time, mainly on lines B and R, and at the western end of C. Perhaps of greater interest was the recording of *R. robusta* Norman on two records for B in October, 1936.

Chaetoceros spp. (CH in Plates XXXVII–XLIV.)

We have found it necessary to deal only with the genus, although in 1936 and 1937 it has been subdivided into Hyalochaetes and Phaeocerids, of the latter group *Ch. borealis* Bailey being the most prominent in this work.

As might be expected they have had a wide distribution as a group, being found in every month, but never on line R in December. The quantities found on B in 1936 and particularly 1937, and on R and C in 1937, were very much greater than in any of the earlier years, there being, *e. g.*, at least an intermediate patch on C in every month of 1937. Most of the larger patches were found in spring, but some occurred in the autumn. Although widespread in space, most patches have appeared towards the ends of C (*i. e.* near the edges of the Dogger Bank), widespread over B and at the eastern end of R. We should note the exceptionally extensive productions in 1937 on C in March and April, and on B in March, June and October: they were also extensive on R in April and May, 1936. In addition there is the unusual appearance of a patch at the western end of line R in September, 1937, this being an area which is usually devoid of diatom patches.

Although they very often appear in great numbers alone, they have been frequently mixed with large numbers of Thalassiosira, *Thalassiothrix nitzschioides*, *Asterionella japonica*, *Rhizosolenia alata* and *h. semispina* and other forms in varying proportions.

Biddulphia aurita (Lyngb.) (BA in Plates XXXVII–XLIV.)

Although this is a small form, the major patches have usually been so dense that it is unlikely that any important ones can have been missed. It has had a very limited distribution in time, viz. February and March, 1933–37, January, 1933, 1935 and 1937, April, 1935–37, May, 1933–35, August, 1932, October and September, 1933, November, 1935, and December, 1932 and 1933. In view of other features of this survey, it may prove interesting that all the more unusual occurrences have been in the earlier years, the later appearances being limited to February, March and April, *i. e.* the months in which patches have been most common. The years 1936 and 1937 had the most extensive productions, although 1933 produced by far the densest patch. All have been limited to the eastern ends of lines B and R, and the western ends of B and C. Although often dominant, it has commonly been found with *Asterionella japonica* and some other early spring forms.

B. regia M. Schultze, *B. mobiliensis* (Bail.) Gran in Van Heurck, and *B. granulata* Roper. (BR in Plates XXXVII–XLIV.)

The three species have been grouped together for this survey, but it should be quite possible to separate them in the future, thus providing more information regarding their little-known relationships and distribution. There is no doubt, however, that most of the significant patches have been restricted to the former two species and mainly to *B. regia*. As a whole they have been seen in every month and were undoubtedly most widespread in 1937, 1933 being second and having the denser patches; there were no patches in 1934. No patches were found on line C, and on B and R almost all were restricted to the east, and were limited to the spring and the autumn.

B. rhombus (Ehr.). (BRH in Plates XXXVII–XLIV.)

This has been found most frequently on line B, less often on R, and rarely on C. The occurrence has been mainly autumnal; 1934 and 1935 were probably the dominant years on B, with 1937 on R. It has been scarce on the whole.

B. alternans (Bail.) Van Heurck. (BT in Plates XXXVII–XLIV.)

This has been very scarce until the autumns of the years 1935–37, there being only one earlier observation. Mainly it has appeared near the eastern ends of lines B, C and R. The only patch occurred on B in September 1937.

Other species of Biddulphia.

In addition to those mentioned above, *B. obtusata* Kutzing, *B. favus* (Ehr.), *B. vesiculosa* (Ag.) Boyer, and *B. arctica* (Brightw.) Boyer have all been found. They were mainly on R in 1935, although *B. favus* was found on B from 1934–36.

Bellarochea malleus Van Heurck. (B in Plates XXXVII–XLIV.)

Because this is a chain form rarely showing less than ten cells at once, it has been thought most suitable to consider only the major patches. These have occurred mainly on line B, less often on R: only rarely have traces been found on C. Whilst it has been found in all months on B, it appeared only in the autumn on C and R. The distribution has been definitely coastal, mainly at the eastern ends of B and R, spreading centrally on occasion. We may note the unusual occurrence of a patch to the west of the centre of R in September, 1937. 1935 was the maximal year on B and 1937 on R, the former providing much the greatest extension and numbers. Patches were absent in 1932 and 1936. Generally it has not been associated with the other forms reviewed in this section.

Cerataulina Bergonii H. Pérag.

Although no significant patches have been recorded, this form has been seen fairly often in the later years (particularly on line C), and generally in the spring and autumn. Owing to its fragile nature the apparent absence of this species in 1932 and 1933 should not be given too much weight; in these years the rolls were stored for a considerable time before analysis.

Ditylium Brightwelli (West). (D in Plates XXXVII–XLIV.)

This has been found at times in the midst of dense patches of *Biddulphia sinensis*, and in these conditions it is possible that some of the lower values may be too low, but it is unlikely that any appreciable patches have been missed and, in fact, the only ones to be recorded were in the spring and autumn of 1937, near the centre of line B. The traces have also tended to appear at these seasons. It has been scarce on line R and very scarce on C.

Eucampia zoodiacus Ehr. (U in Plates XXXVII–XLIV.)

This has had an interesting time distribution since no patches were found until 1935, when they appeared on all three lines. It was definitely maximal in 1936 and scarcer again in 1937, and was limited to the northern lines in these years. With the exception of the one patch in July, 1935, it has been scarce on line R, being entirely absent in 1933 and 1934 and nearly so in 1936. Some patches appeared in the spring, but most have been in the autumn, the only July findings being in 1935. They have been most evident at the eastern and western ends of B and C, and the eastern end of R. The unusually dense production in the autumn of 1936 will be referred to again in relation to other features of the survey.

Asterionella japonica Hassal. (A in Plates XXXVII–XLIV.)

We have found this diatom throughout the year, although only once in July (on line R in 1935). It has been most abundant on B (1936–37), and least on R, being absent in 1933 and only once seen in 1934, although it was abundant in 1937. Patches were mainly limited to the spring in the early years, but appeared in the spring and autumn in the later ones, the spring patches always being the denser. Generally they have been found over the western ends of B and C, and even over the western half of R in 1936 and 1937. Fairly often they have been mixed with large numbers of Thalassiosira, Chaetoceros, Thalassiothrix and Navicula species.

Thalassiothrix species. (TX in Plates XXXVII–XLIV.)

Whilst it is safer to limit this group to the genus, it does in fact consist mainly of *Thx. nitzschioides* Gran, and only small numbers of *Thx. longissima* Cleve and Gran have been seen over the eastern half of line C (*e. g.* autumn, 1937). *Thx. Frauenfeldii* (Gran) Cleve and Gran has not been recorded, although the separation of this from the first presents well-known difficulties. At least it is certain that it must have been relatively rare.

The group has been found at all times of the year and patches on each line from 1934 onwards, mainly in the spring, but also in the autumn. On line C they were most abundant in 1937 with 1934 second; highest numbers were attained on B in 1936 and 1937 and on R in 1934 and 1937. The patches have been commonest over the ends of the lines although none have been found over the western ends of R. Unusually extensive patches appeared in 1935 on C, and in 1937 on B and C in March. It has seldom been found " pure ", but usually with Chaetoceros, Thalassiosira and Asterionella species.

" Naviculoids ". (N in Plates XXXVII–XLIV.)

Under this very wide head are included a number of Naviculas and Fragillarias, and occasional other small chain forms which have presented great difficulties for identification on the recorder rolls. However, there is some order in the distribution, and the observations for the whole may have application with the rest of this data. They have been present at all times of the year and patches have appeared on all lines, but only on C in 1933 and 1935, on B in 1935–37, and on R in 1936–37. They have been mainly found in the spring, and have appeared exclusively at the western ends of B and C, but at both ends of R. (The only occurrence at the western end of R was in June, 1937.) Whilst sometimes " pure ", they have usually been mixed with Thalassiosira and Asterionella species.

Gyrosigma species.

This includes all the sigmoid diatoms (mainly limited to a few types commonly found along with Paralia, etc.). They have been found on all lines and in all months, but generally more abundantly in 1935–37, the only patch appearing in 1937 on the extension of C past the old terminus.

Bacillaria paradoxa Gmel., Van Heurck. (BCA in Plates XXXVII–XLIV.)

No patches were found until 1936, and 1937 had by far the greater number, most of them appearing in the spring and the autumn; it has been found in all other months excepting January (but only once in December). It has been very scarce on line C and most abundant on R, where most of the patches appeared over the eastern half, as did also the few on B. The most extensive production has been in March, 1937, on R, and it has most usually been found along with *Thalassiothrix nitzschioides*.

Nitzschia species.

These are very small diatoms and, since the most usual species, *N. closterium* Ehr., is not a chain form, it clearly cannot be caught in anything like representative numbers by our silk, although under certain conditions it can be very plentiful, the presence of Phaeocystis being the most striking. Thus, whilst our records show it to have been present in most months and on all lines, its chief abundance has been in the spring, when Phaeocystis is also abundant. For this reason it would be dangerous to discuss variations, since they are here more evidently affected by possible arbitrary conditions than in any other form (the general scarcity of other forms in the presence of dense Phaeocystis suggests that this is not likely to play a large part in disturbing their apparent distribution).

It is difficult to decide whether the Phaeocystis acts as a very fine filter or whether there is an association between these forms (*e. g.* see Gran, 1902). Ostenfeld (1931) did not find any form other than *N. seriata* to be of sufficient importance to be included in his résumé under the criteria there adopted, thus implying that Nitzschia as a whole had been much rarer than Phaeocystis, which is included; on the other hand, it has been seen in apparently very close association. It must be remembered that Phaeocystis might act as an efficient filter when using tow-nets, as well as with the recorder, and that the apparent association might merely be due to this factor. The point is of interest and worth investigation in the future, but meanwhile we can record that it is not always found in the presence of Phaeocystis, and that sometimes moderate numbers may appear in its absence (or relative scarcity). Even on the same record (*e. g.* on line R in June, 1932) at one end Nitzschia may be very abundant and at the other very scarce in comparison. As a result of such distributions it became apparent that at times the Phaeocystis " jelly " may owe much of its coloration to the presence of the diatom (or has developed it in association), and in some rolls where few or no Nitzschia have been present the flagellate has appeared as an almost colourless jelly.

In the presence of Phaeocystis the usual form is found to be *N. closterium* (Ehr.), generally in a very slender variety (at times so slender as almost to suggest the possibility of another species); there may, at times, be relatively enormous numbers. In the normal way no attempt has been made to estimate the numbers, since they are considered to be unduly arbitrary, but the numbers have sometimes been so great that an estimate has been attempted of one of the thicker patches and this suggested a density of some 500,000,000 cells per cubic metre, or 500 cells per c.c. Any such calculation must be considered minimal because (1) it was assumed that the maximum volume of water has flowed through the machine, and this is unlikely in view of the clogging of the silk by Phaeocystis; (2) possibly not until the Phaeocystis has attained a certain density would it begin to filter the diatoms; (3) the calculation had necessarily to be made from the observed volume which is itself minimal for reason (1) above; and (4) there would be a loss as the result of scraping off the plankton prior to measurement. Clearly, at times the actual density of this form must be very great—much greater than is usually considered possible outside such waters as those of Loch Striven or Kiel.

N. closterium is almost as often recorded on line C as on B and R, although on the first line Phaeocystis is very scarce; it thus appears to be commoner in the open waters of this area than has usually been thought. Other species have been found, of which *N. seriata* has probably been the commonest, and although it has never been abundant, it was probably most evident in 1937, whereas if we consider only the areas of denser Phaeocystis, it is probable that *N. closterium* was most abundant in the earlier years.

Other species.

Corethron criophyllum Castr. has been seen on lines B and R in 1932 and 1933. *Streptotheca thamensis* Shrubs. on B, C and R in the autumns of 1936 and 1937 ; similarly *Hyalodiscus steliger* Bailey. *Melosira Borreri* Greville and *Stephanopyxis turris* Greville have both occurred, the former most in the earlier years and the latter probably more abundant in the later years Other species which have occurred from time to time will be seen in the representative list on p. 78.

General Annual Distribution and Variations.

We may now consider the general cycle of diatom production throughout the year. The records of the intermediate and major patches are shown in Plates XXXVII–XLIV, which should enable one to have in view the main seasonal developments in these waters.

Reference to the maps and the general Record List in ‘ Bulletin ’ No. 2 will show that from time to time a record is absent on one line or another, and it is clear that such omissions may seriously disturb annual comparisons, either for individual species or for the general distribution for the area. Such omissions have probably been most serious during the months of February and May (*e. g.* on R) during the earlier years and probably contribute towards the relative sparsity of those years, yet we should note that on such records as are available for these periods there is a similar scarcity. Similarly the spring months were not too well sampled on line C. Further, it must be remembered that the recorder will normally record only the denser patches of phytoplankton, and that as a result it is often possible to obtain records showing no patches and which are almost entirely blank. It must not be thought that such records really indicate that no phytoplankton was present (even of the species which are usually caught by the machine) ; they merely indicate the relative scarcity of the phytoplankton.

As elsewhere in this paper, it will be assumed that the charts will speak for themselves, and the notes will be limited to emphasizing points which are considered of significance and which will be referred to in later papers.

January and February :

The records are generally thin, but we may note the persistence into January, 1936, of patches of *Rhizosolenia* (*alata* and *h. semispina*), which are almost certainly derived from similar patches in December, 1935 (*cf.* also *R. styliformis* : this form, together with *B. sinensis*, may also “ carry over ” from the previous year.) In February, 1937, there is a western patch of *Biddulphia aurita*, etc., which will be seen to anticipate the typical formations of March ; similarly an Asterionella-Navicula patch near the Maas appears to be an early development.

March :

It is clear that the growths in the earlier years appear to have been slighter than in 1935–37, and this appearance is reinforced by the associated differences of flora and distribution. The typical growths in the earlier years were eastern, whilst those of 1935–37 were more in the west : whilst Coscinodiscus and *Biddulphia regia* were important in 1933 and 1934, the significant forms in 1935–37 were Naviculoids, Asterionella, Thalassiosira, *Biddulphia aurita* (also present in 1933, but in the east), and Thalassiothrix, with Skeletonema in 1936 and 1937 and Chaetoceros in 1937. Amongst the later years we may note the much more widespread patches on lines B and C in 1935 and 1937, and the central patch on R in 1937.

It will be remembered that patches of *B. sinensis* are not uncommon in this month.

April :

Such differences are found again in April, when the general numbers tend to be rather lower. In 1934 a patch appears which should be related to those found typically in March, whilst from 1935 onwards several forms (*Rhizosolenia Shrubsolei*, *R. Stclterfothii* and Eucampia) appear which are more typical of later months. In 1937 we may note the absence of Coscinodiscus and, as in February and March, the unusual extensions of Bacillaria along the Dutch coast.

May :

Chaetoceros, which was probably the dominant form in April, is very widespread again in May, commonly in association with *Rhizosolenia* (*alata* and *h. semispina*) in 1933, 1934 and 1936. *R. Shrubsolei* and *R. Stolterfothii* are common, and we may note the presence of Eucampia in 1935, 1936 and 1937. The omission of several important records in May renders comparisons difficult, but in view of some other observations we should note the presence of central patches on line R in 1936 and 1937.

Reference to plates XXII to XXXVI will show also that patches of *R. styliformis* and *B. sinensis* are found in these months.

June :

Numbers are very much lower on the whole, although there are still extensive growths in 1937. There were no patches in 1932 and 1933, and very few in 1934, whilst another difference is seen in the unusual appearance of patches at the western end of line R in 1937. We may note again the persistence of small patches of Bacillaria throughout May and June scattered in the Dutch coastal waters : otherwise Chaetocerids and Rhizosolenia spp. were the typical forms.

July :

Once again the early years are blank, and in 1935 patches were very few. The dominant forms are Rhizosolenia species, as in June, but we may note also the presence of Eucampia in 1935 and Guinardia in 1937. In this month and sometimes in June we may note the small patches of *R. styliformis* which usually extend into August and appear to be forerunners of the autumn patches.

August :

Only *Rhizosolenia alata* and *h. semispina* were found up to 1935, other species appearing in 1936 and 1937, amongst which we see Bacteriastrum in both years, the persistence of Guinardia and the first appearance of Bellarochia in 1937. In the last year Bacillaria shows a general increase, whilst in some years we find the first of the autumnal patches of *B. sinensis.*

September :

Bellarochia is a typical form, and is the only one in the earlier years. We should note its absence in 1936 and the unusually large development of Eucampia in that year. There is also an unusually strong growth, mainly of Asterionella and including Bellarochia, over the western half of line R in 1937.

In this and the next two months we must bear in mind the large patches of *R. styliformis* and *B. sinensis* which may appear. They also were generally more abundant in 1935–37, and it may be significant that there appeared to be some reciprocal relation between the numbers of the first and those of Eucampia. Whilst both were abundant in those years, in 1936 *R. styliformis* was scarcer on the whole and very late in appearance, whilst Eucampia was most abundant in that year, and in September and October was plentiful in the area usually occupied by Rhizosolenia.

October :

Apart from *Rhizosolenia styliformis* and *Biddulphia sinensis* there were practically no patches in the first three years, but many forms show small patches in 1935–37. The Rhizosolenia spp. persist, together with Bacteriastrum and Eucampia, whilst there are signs of further growth of Thaliassiothrix and *B. regia.*

November and December :

Again the characteristic difference lies in the smaller numbers of the earlier years. Rhizosolenia and Thalassiothrix are typical species, but we should perhaps note the rather early growth of Naviculoids and *B. aurita* in December, 1933. *R. styliformis* and *B. sinensis* are now decreasing and generally situated more to the north-east, but they may well persist into the next year.

General.

It will be seen that there are certain trends common to all the years to a greater or lesser extent. These include the production of spring patches, based on *B. aurita*, Asterionella, Naviculoids, Thalassiothrix and Thalassiosira, and leading up to a dominantly Chaetocerid complex. This is followed by extensive productions of Rhizosolenia spp. in the late spring, smaller numbers throughout the summer and further development in the early autumn in association with, or followed by, secondary maxima of certain of the spring forms, and the appearances of other forms, such as Bellarochia, Bacteriastrum, *B. sinensis* and *R. styliformis*, which are normally only found in the autumn as large patches. On this basic theme, which is essentially in agreement with the findings of earlier workers, there are large numbers of variations in the annual cycles, and it is by means of these that we should ultimately be able to characterize the different years, relating the differences to hydrological features and to variations in the commercial fisheries. Such characters have been the variable appearance of patches of Coscinodiscus, the extensive production of Bacillaria along the Dutch coast in 1937, the unusually high production of Eucampia in the autumn of 1936 in association with the much lower production of some other forms at the same time. In addition we may note the more extensive productions in the later years, and in particular the apparently unusual (within these records) production of patches in 1936 and 1937 over the generally barren area between the Dudgeon and the Newarp Light-vessels. These last features are summarized in Text-fig. 10, showing the overall numbers of patches[1] over the different parts of each line for each year from 1933–37. These figures present only the most tentative assessment of the overall numbers, based upon the number of occasions in each year that patches of different diatoms have been recorded in different parts of the area. No allowance is made for the varying size of the forms, nor can we allow for the occasions when a region has not been adequately sampled at a time when large patches may have been present (*e. g.* the spring of 1936 on the C line). Apart from the obvious difference of the total quantities there are quite striking differences in position: during the first years the diatoms tended to appear more at the edges of the Dogger Bank, whereas in 1936 and 1937 they have been more widespread and even central. On B line there has been an increasing development of westerly patches with the passage of time, and on R, as we have seen, a similarly-marked westerly progression has occurred.

In general there is a contrast between the years 1932–34 and 1935–37, the early years and the last being extremes in many examples, yet, although there is this difference, it is not progressive in all respects, and in many features 1936, for example, tends to be somewhat retrogressive, whilst 1935 and 1937 are more similar. Also the year 1934 is perhaps less like the later ones than is 1933. Many of the characteristics seen in reviewing these forms may remind the reader of those found in discussing the diatoms, *R. styliformis* and *B. sinensis* and to be seen in the

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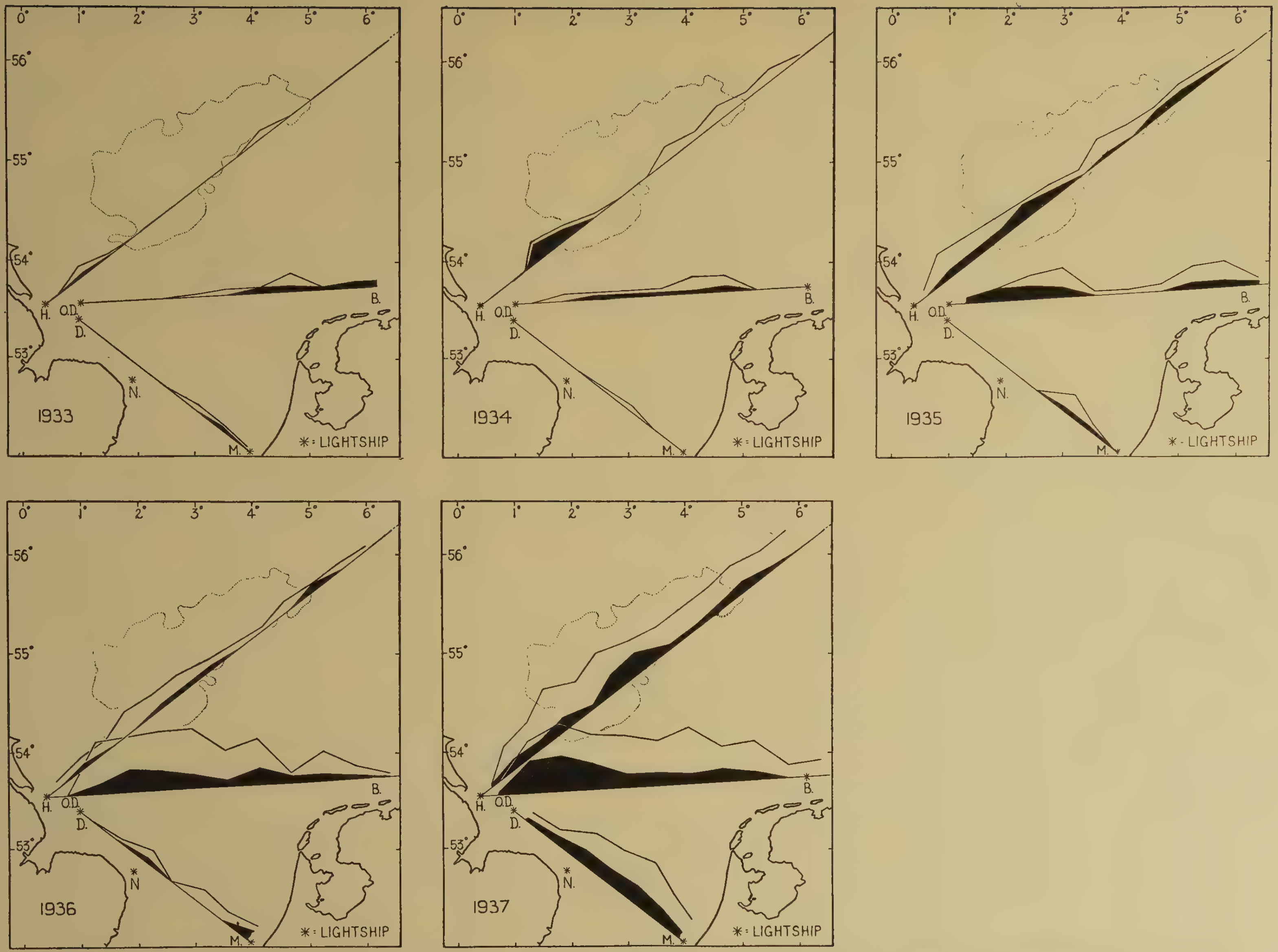
[1] *i.e.* of patches of diatoms other than *R. styliformis* and *B. sinensis*.


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
1933
1934
1935
1936
1937
✳ = LIGHTSHIP

TEXT-FIG. 10.—Charts showing the broad indications of the varying productions of the diatoms other than *Rhizosolenia styliformis* and *Biddulphia sinensis* during each of the years 1933 to 1937. The occurrence of medium patches is indicated by the continuous open line and major patches by the blacked-in line. For further explanation see text.

Dinoflagellates and Phaeocystis, and there seems little doubt (see later) that such common differences are to be related with significant changes which can be shown for the current systems of the area during this period.

DINOFLAGELLATES.

For the first few years the Dinoflagellates (practically all Ceratia) were necessarily treated as a whole group ; later it became possible to subdivide them. Not all the records of 1935 were so treated, but with one or two exceptions in the early part of 1936, when the group was scarce in the plankton, the data for 1936–37 has been. From 1938 onwards a more detailed treatment is being adopted. In order to maintain continuity over the whole period distribution graphs and serial charts have been presented for the whole group, and much of the discussion must necessarily refer to these as the only consistent data. When using the graphs one should remember that they have not been plotted on the same vertical scale as that adopted for the rest of the phytoplankton. Comparison of Plates XVII and XVIII (in which some totals for 1935 are shown on the new scale), with Plates XI and XII (the standard graphs for totals on the usual scale) will show the relationship between the results from the two methods. That for the whole group emphasizes the maximum, whilst the variable scale used for the species emphasizes the smaller patches by exaggerating their scales relatively, although the maxima are still clearly shown.

Bremen Line :

The distribution is shown in Plates XI and XII along with that for Phaeocystis, the Dinoflagellate graphs being blacked in. The arrangement of these graphs is similar to that of those already seen with the exception that the asterisks here denote the absence of patches, since traces are usually so common that they have not been shown. In January, February and March the numbers are usually low, but we may note small easterly patches in 1934 and 1936, and more central ones in 1937. The first significant patches have usually appeared in April and early May, the numbers increasing rapidly to a maximum in May or June. The greatest numbers have been mainly central in 1932–34 and 1936, more westerly in 1935, and mainly eastern in 1937, although more or less appreciable growths have been found elsewhere in all these years. Later development has varied, there sometimes being a decline after the maximum, followed by a recovery, although this was not evident in 1933 and 1936, and was less marked in 1935. In general the patches composing this second maximum have been over the eastern end of the line, and in 1935, a typically western year in general, these patches were close to the Borkum Light-vessel, and included one of the densest recorded on the line.

The limitation of most of the 1935 patches to the west seems worthy of note, the highest numbers on this line appearing in a similar position from the end of

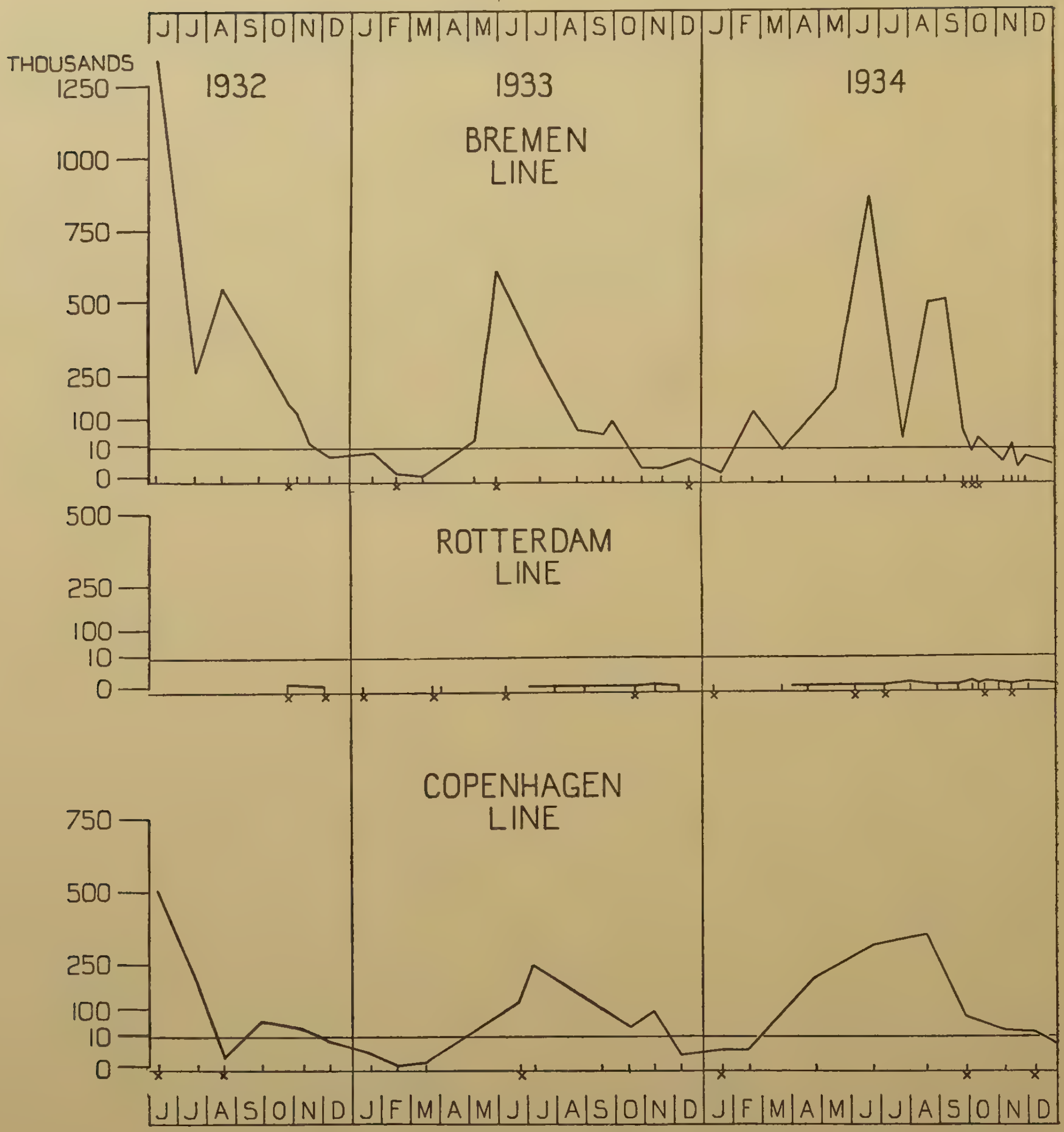
April to mid-August, after which they rapidly declined. In 1937 the main patches were confined to the east, and unusually large numbers were found in that year.

Quantitative variations may be seen more clearly in summary form in Text-fig. 11. In distinction from the diatoms there is a less evident increase in quantity over the period of the survey; although the numbers in 1937 were very high, those for the partly sampled year 1932 must have been nearly as high and possibly higher. The year 1933 presented the lowest concentrations. This diagram also brings out the seasonal variations already noted, and we see that except in 1933 and 1936 the graphs show two modes: this is a reflection of the early autumn decrease and recovery already noted being most marked in 1934 and 1937, and less so in 1932 and 1935. We may also draw attention to the very slight peak at the end of September in the 1933 graph. It is proposed to refer to the two modes as the "Primary", being the earlier and larger, and the "Secondary"; reference back to the annual graphs will show that the secondary peak has been due mainly to an increase in the easterly components of the patches (in 1937 there was the exceptional large westerly patch at this time also).

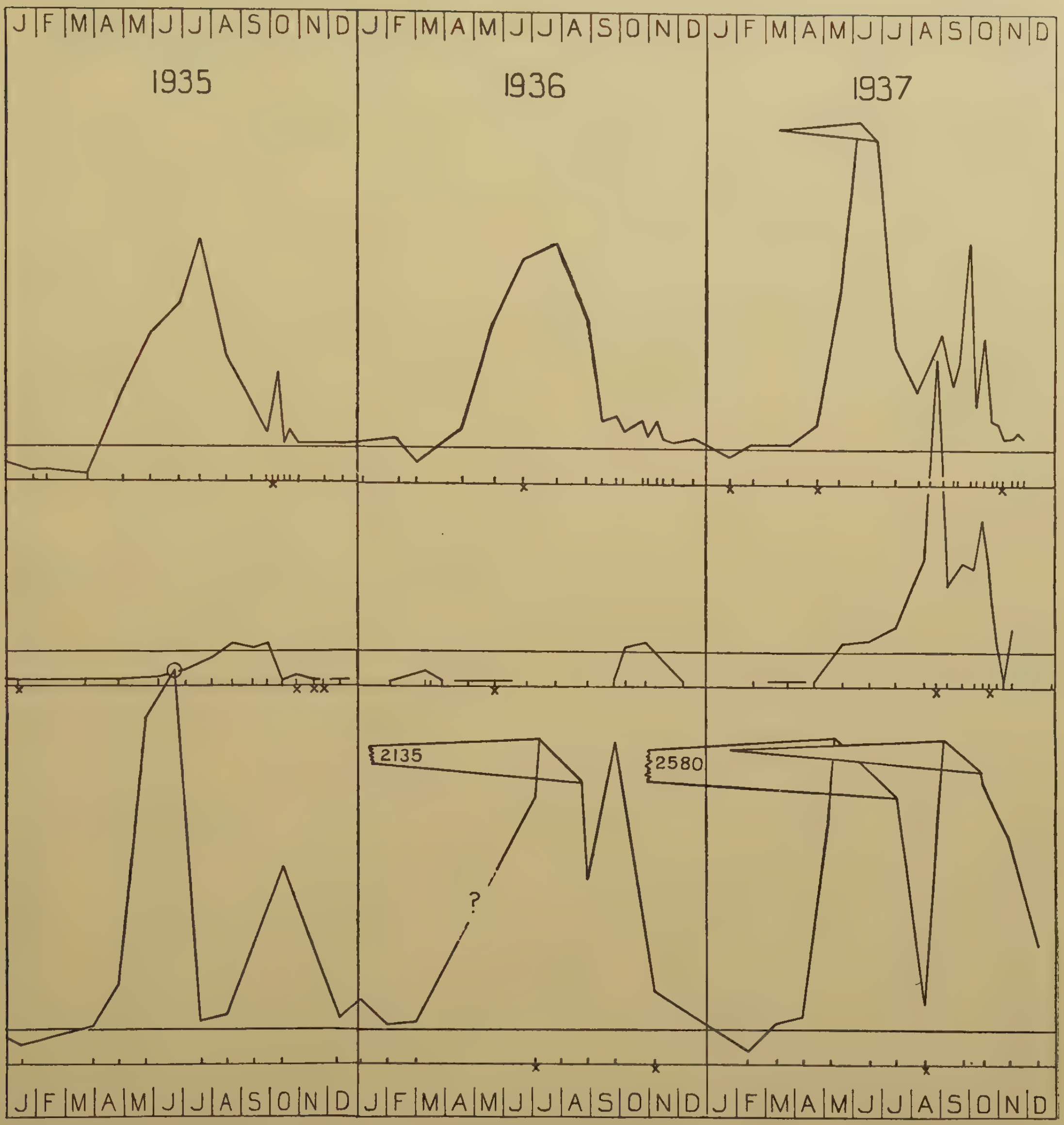
Copenhagen Line:

The distribution is shown in Plates XIII and XIV. As on the Bremen Line, the numbers were very low in January, February and March, but such records as we have for April showed an increase. This continued in May, leading to maximal numbers in June or July. Again in some years this has been followed by a decline and subsequent recovery (clearly shown in 1935–37), but in other years only a decline. In October, November and December the numbers have always been lower again, although in 1937 they were relatively very high for this period.

In this main development towards a summer maximum the annual cycles have been reasonably similar, but differences may be seen, both in the numbers found and in the spatial arrangement. From 1932–37 there has been an increasing tendency for the records to be dominated by patches at the eastern or western ends of the line (*i. e.* near the old termini for this line, although in 1937 we also recorded large patches to the east of the old terminus). The year 1935 was interesting in presenting some rather regular features. At the end of March there were small eastern and western patches and, as far as our records go, such patches (particularly the western ones) are found within a small area from record to record. Although there was no western patch in April, well-defined traces were present, and a small patch in May is followed by a dense one in June, small ones in July and August, denser again in September, and smaller ones in October and December. The eastern ones are not so regular, but the series as a whole makes it necessary to recall a rather similar persistence of patches and traces of *R. styliformis* on the Bremen Line over a similar period. If such regularity is not so apparent in 1936 and 1937, yet the terminal patches are even more obvious, the western ones being dominant in 1936 and the eastern ones in 1937.



Text-fig. 11.—Graphs showing the fluctuations in the total numbers of Dinoflagellates recorded between June, 1932, and December, 1937. The records for the Bremen line (between Outer Dowsing and Borkum light vessels), the Rotterdam line (between E. Dudgeon and Maas light vessels) and the Copenhagen line (from Humber light vessel for 250 miles towards the Hanstholm) are shown separately. Above and below are time scales in months: J., F., M., A., etc. Each point on a graph represents the total number of Dinoflagellates found on one record: the exact position of each record in relation to the time scale is shown as a small vertical line against the base line of the graphs. The scale of numbers is in thousands per record, with an exaggerated lower end below the true base-line, as in Text-fig. 5. Records covering less than half the standard distance (see above) have been omitted unless where indicated as an open circle; records covering less than 80% are indicated by an ×.



TEXT-FIG. 11 (continued).—(The very high peaks in 1936 and 1937 are shown folded over to the left for space economy.)

The general arrangement and some annual variations are emphasized in Text-figs. 12 and 12*a*, showing the maximal quantities from year to year. The varying weight of the easterly and westerly components is brought out (we must allow here for occasions when one or other end of the line has not been sampled), and also that of the more or less marked central one (often due to patches at the end of the year). The overall graph for the period shows how the greatest numbers have been found in the east and the west.

Unlike the Bremen Line there was, on the whole, a progressive increase in numbers over the six years. In some years there was a marked fall in numbers and a later increase in the early autumn, as is more clearly shown in Text-fig. 11, giving the total numbers on the line month by month. In 1935–37 we have the best examples, the secondary modes being very small in 1932 and 1933, and, if present, only appearing as a slight inflection in the general downward slope in 1934 ; the dip in 1936 was appreciably less than in 1935 or 1937. The fact that these bimodal tendencies should appear in Bremen records and in Copenhagen records suggests that they may have real significance. The progressive increase in numbers is shown to begin probably in 1933 (there is little doubt that the poorly sampled 1932 should have produced much larger quantities than 1933), and it extended to 1937.

Rotterdam Line :

The distribution is shown in Plate XV (continuous line), a characteristic being the usually low numbers compared with those of the previous lines. The low numbers of 1932–36 (and particularly 1932–34) are the more pronounced in view of the relatively very large numbers found in 1937. Whilst patches were almost absent in 1932–34, the numbers were relatively quite high in 1935, and patches were found on several records. In 1936 they were lower again, only one patch being found.

Dinoflagellates have been found on all parts of this line, but larger numbers have occurred in the eastern sector. Although occurring all the year round, they have been more numerous in the summer and early autumn. In 1935 the patches were limited to the eastern side of the line. In 1937 they spread well over to the west, beginning in May with a small easterly patch ; larger ones in June and July were in the centre, followed by still larger patches from August to October, which were at first eastern and then bimodal (east and centre), the bulk lying near the Maas Light-vessel. Only a smallish patch was found in November and only traces in December.

The differences between the six years appears most definitely in Text-fig. 11, if we consider that part of the graph lying above the true base-line (see p. 92). The quantities in 1932–34 were so small that they would not have been visible above the true base although they appear here on an exaggerated scale below it. In contrast 1935 and 1936 appear above the line (1936 being lower than 1935) whilst for all the shortness of this line the year 1937 provides a graph comparable with those of B, C and H. The relatively enormous increase found should indicate a change of fundamental importance during the period, and this is emphasized by the recording of numbers similar to those of 1937 in 1938.[1]

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[1] See, however, Addendum on p. 168.

Esbjerg Line:

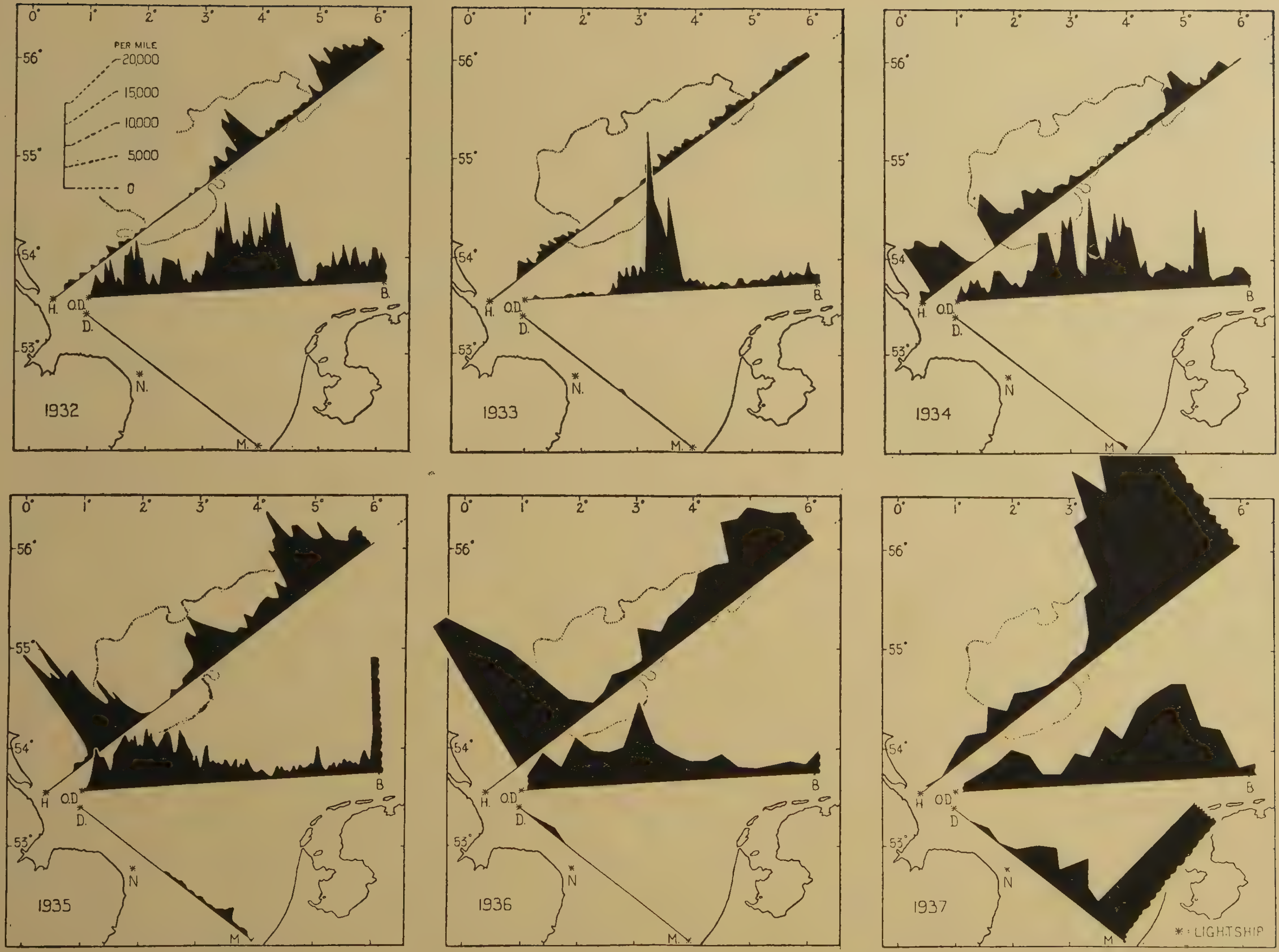
The data on the whole show a cycle similar to those already seen, there being a summer and early autumnal maximum. In 1937, the only year adequately sampled, the bulk of the Dinoflagellates were found to the east of the centre, although patches extended almost to the Sunk Light-vessel (Plate X). We may note also the particularly dense patch near Graadyb at the end of July.

Distribution over the Area.

The serial charts for the Dinoflagellates are shown in Plates XLV to LVII, the graphs being blacked-in in contrast to those of Phaeocystis in broken line.

In March and April the first small patches usually appear each year and are typically at the eastern and western ends of B and C, being perhaps most evident in the east. Thereafter there is a great increase in numbers until June, and the main trend of events has taken three main courses during the period ; in 1932–34 and in 1936, whilst there are still greater or lesser eastern and western components (mainly on C), the bulk has been found on the centre of B and there were appreciable central patches on C, although no patches were found on R. In 1935 and 1937 one or other of the eastern or western components dominates the picture, primarily the western in 1935 and the eastern in 1937, whilst in the latter year also the first patch on R was found, in the east. During July there is generally a decrease in numbers (in August in 1936), whilst in the following months there has been a more or less marked recovery in 1932, 1934, 1935 and 1937, particularly in 1937 if we include under the head of " recovery " the enormous increase on R at that time. During the month of July the characteristic distribution of the years was generally maintained, although in 1936 we can note the dominance of the terminal components on C. Later the numbers tend to decrease (the month varying according to the year), and by October the bulk tends to be in the east on one or more lines in each year, although at different times we can note the appearance of patches near the Humber (also on R in 1936 and 1937). In contrast to the only other significant patch on R—October, 1936, in the west—the eastern growths in 1935 and particularly in 1937 form important deviations from the " normal " as seen during the period. In November and December patches are generally low and scattered, but progressively larger and more abundant during the period. Those of January and February, which seem logically to be connected with the previous years' growths, are fewer and scattered, February probably providing the termination of the cycle for these forms as a whole.

The deviations are here perhaps even wider than in the previous forms discussed, and this may well be due in part to the heterogeneity of the group. Some have been necessarily pointed out in reviewing the course of the annual cycles, and other details must be left until they may be referred to in relation to other factors, but in Text-figs. 12 and 12*a* some of the differences are emphasized graphically. Text-fig. 12*a* shows the maximal numbers found on all parts of the lines during


PER MILE
20,000
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6°
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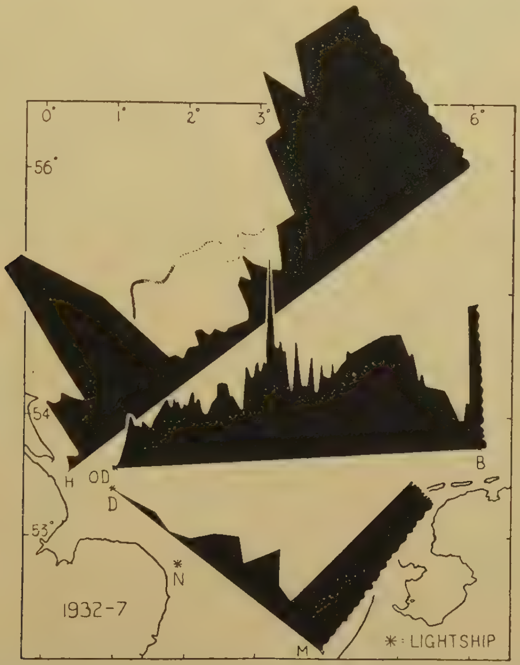
54°
53°
H.
O.D.
D.
N.
M.
B.
1932
1933
1934
1935
1936
1937
* = LIGHTSHIP

TEXT-FIG. 12.—Charts showing the maximal quantities of Dinoflagellates in numbers per mile (scale inset) recorded in each year at different points along the three lines. Note that 1932 was incompletely sampled.

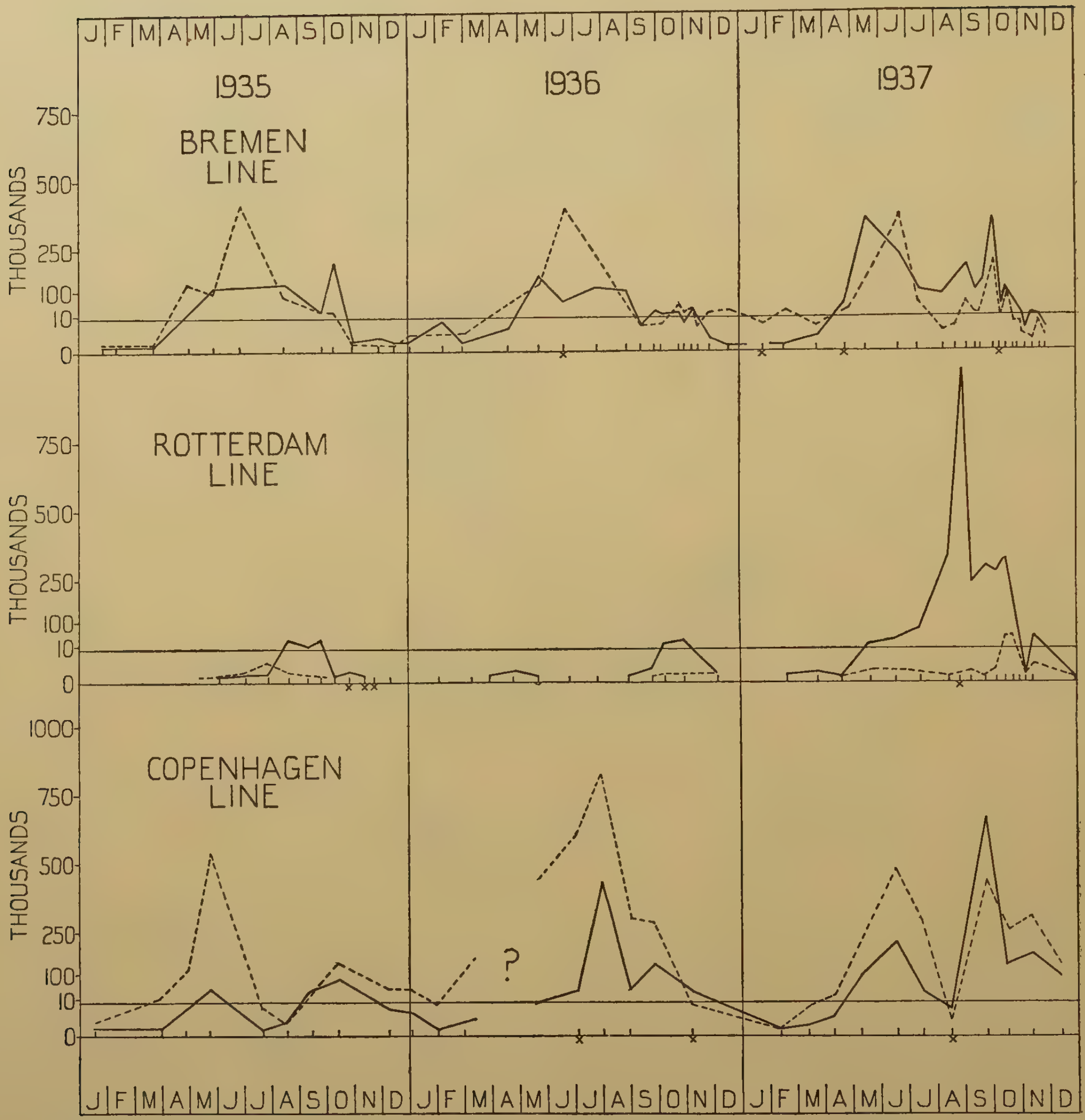
the whole period, and the regions of "maximal" numbers have been over the east of B, C and R, the centre of B and over the west of C. In other words the greatest quantities have been at the edges of the Dogger Bank (to the west, the east and the south) and along the Dutch coasts. Large patches have been rather scarcer in the centre of the Copenhagen Line, over the western half of B and, except in 1937, generally over the Southern Bight. The several years have shown a varying emphasis on these areas which should provide standards for comparison with other forms and other periods.



Text-fig. 12a.—Charts showing the maximal quantities of Dinoflagellates in numbers per mile recorded over the period June, 1932–December, 1937, at different points along the three lines. The separate year charts in Text-fig. 12 are here combined.

Ceratium furca and *C. fusus*.

In view of the suggestions and findings of Gran (1902, 1912) and others (*e. g.* in contemporary literature, Frost, 1938) regarding the biology of the Dinoflagellates and their relations with the physical and chemical conditions of the water, it seems unfortunate that in the more recent investigations they should have been relatively neglected (see, however, Frost, *loc. cit*); for our part we must regret that it was not possible to separate from the beginning the different species, at least those of the Ceratia, although from 1938 we are undertaking this separation in some detail, and we hope in the future to be able to extend it to include varieties of the most variable "species". It is felt that the methods of the recorder are essentially suitable for investigations into specific variation (providing information regarding



TEXT-FIG. 13.—Graphs showing the fluctuations in the total numbers of Ceratium furca (broken line) and *C. fusus* (continuous line) taken on recorder lines between January, 1935, and December, 1937. The records for the Bremen line (between Outer Dowsing and Borkum light vessels), the Rotterdam line (between E. Dudgeon and Maas light vessels) and the Copenhagen line (from Humber light vessel for 250 miles towards the Hanstholm) are shown separately. Above and below are time scales in months: J., F., M., A., etc. Each point on the graph represents the total number of the particular species found on one record: the exact position of each record in relation to the time scale is shown as a small vertical line against the base-line of the graphs. The scale of numbers is in thousands per record, with an exaggerated lower end below the true base-line, as in Text-fig. 5. Records covering less than half the standard distance (see above) have been omitted: those covering less than 80% are indicated by an ×.

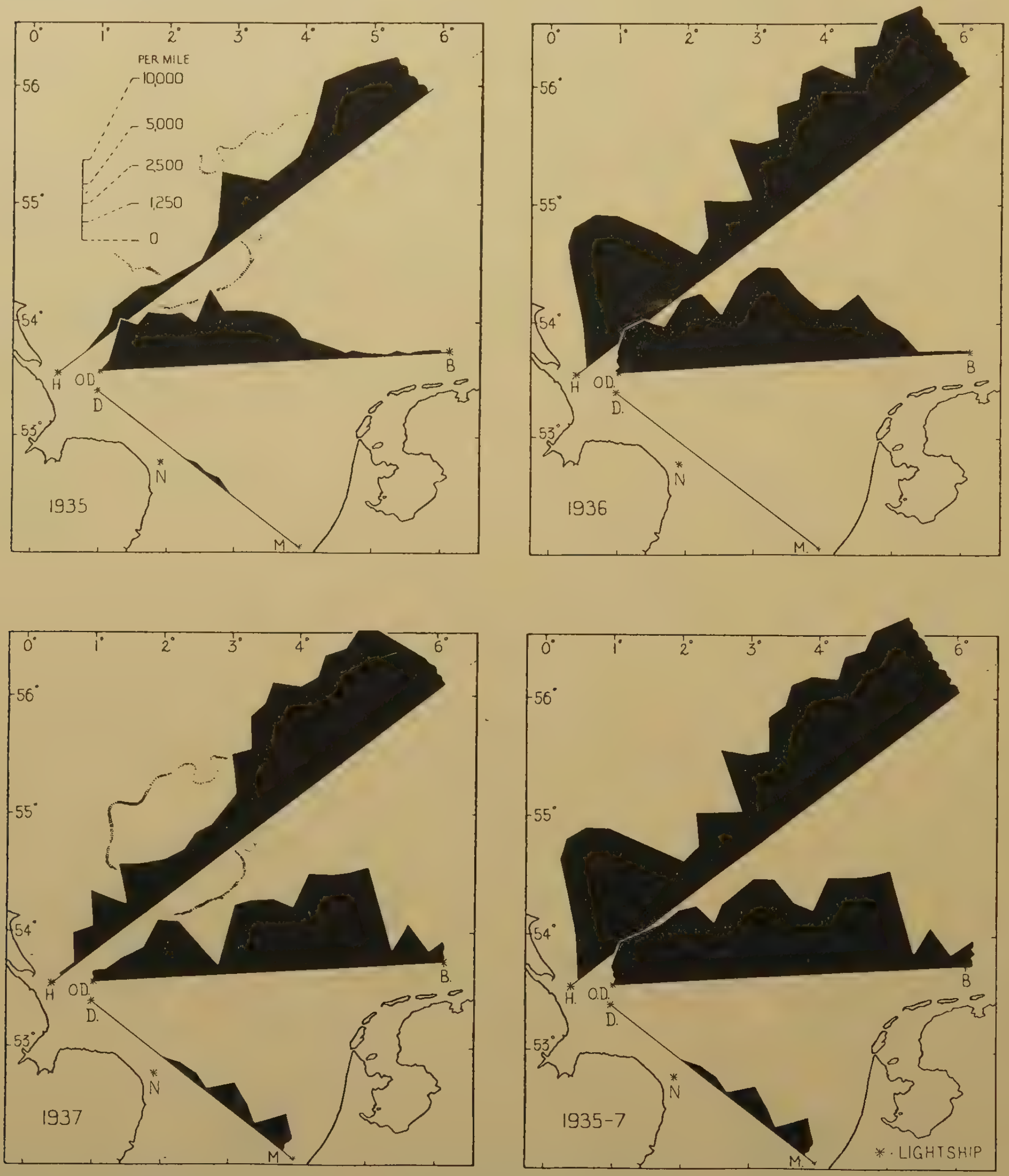
gradual changes in association with the environment), and we hope to be able to make this a feature of the work, since Gran (*loc. cit.*), in particular, has suggested how these may be useful as guides to important differences in water masses—in fact as " indicators ".

Partly in 1934 and 1935, but mainly in 1936–37, we arranged to separate from the rest the Biceratia and *C. fusus*, the former being almost limited to *C. furca* (*C. lineatum*, *C. minutum* and the biceratioid forms of *C. tripos* being scarce in our samples for this area). The Dinophysids and the non-ceratioid Peridiniidae were also usually scarce. It is felt that little of value would arise from a discussion of the heterogeneous group of other Ceratia, etc., so description will be limited to *C. fusus* and what we propose to term for convenience the C. furca group.

On p. 75 we have referred to the analysis of silk scrapings (tube analyses), and from 1932–35 these have given some data, supplemented by notes, regarding the dominant species. This is inadequate for a full description or for graphical purposes, but the chief implications may quickly be summarized. In support it should be said that as far as we had comparable analyses on the roll during 1935 the suggestions from the tube analyses were in general borne out. The 1932 data suggest that on B the proportion of *C. fusus* increased towards the end of the year, and that this form was particularly evident in the eastern patches of the later months. In 1933 it seems to be scarcer, and may only have been significant in the eastern patch of late September on B ; the heterogeneous group of other Dinoflagellates was perhaps more numerous this year than in 1932. The small eastern patch of February, 1934, consisted mainly of *C. fusus*, and throughout this year the form was most evident in the east on B, particularly the " secondary " maximum showing higher proportions ; it appears to have been more abundant than in 1933, and probably there was a higher proportion of the C. furca group than in the earlier years. There seems little doubt that in these years we can say that the earlier patches contained a smaller proportion of *C. fusus* than the later ones. On C, on the other hand, there was no such variation as far as this evidence goes, although there was a suggestion that *C. fusus* was scarce in 1933, compared with 1932 and 1934. The general scarcity of the group on R makes it unnecessary to comment on the species. From 1935 there is more detailed evidence, and we may discuss it in the usual manner in relation to 1936–37.

Bremen Line :

The western patches in May, 1935 (Plates XVII and XVIII) contained a high proportion of the C. furca group, a condition persisting until August, when *C. fusus* had become more abundant ; the western component thereafter diminished in proportion to the others. On the other hand, eastern patches showed a high proportion of *C. fusus* from May, when they first became significant, until October, culminating in one of the densest patches of the year and consisting almost entirely of *fusus*. The general trend is not dissimilar from that deduced for the earlier years, and in particular we see that the secondary maxima have been due to increases in the numbers of *C. fusus*.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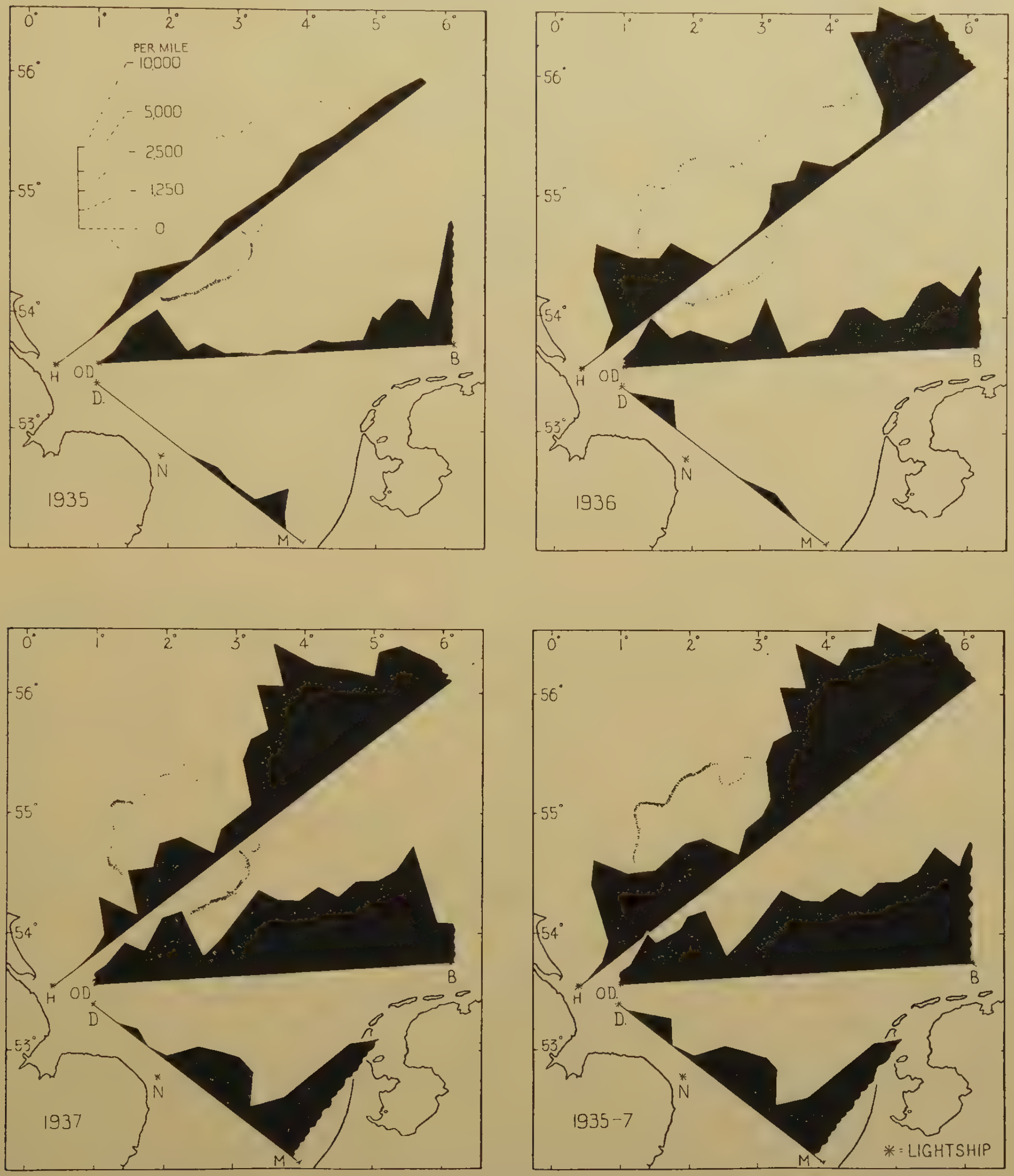
B
1935
1936
1937
1935-7
✱·LIGHTSHIP

Text-fig. 14.—Charts showing the maximal quantities of Ceratium furca in numbers per mile (scale inset) recorded in each of the years 1935, 1936 and 1937, at different points along the three lines together with a chart combining the three years.

In 1936 a somewhat similar sequence occurred, but the summer patches were central. The furca group was dominant over *C. fusus* in these, but we should note an eastern patch of *fusus* in May, and its relative abundance in the east from

August, or earlier, although there were no distinct primary and secondary maxima this year. In 1937 the whole Dinoflagellate complex was more easterly, and this is necessarily reflected in the distribution of these forms: usually the dominant one is *C. fusus*, and it is probable that these two facts are associated. In no previous year has *fusus* been so abundant in the early part of the year, but whilst this was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OD
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1935
1936
1937
1935–7
✱ = LIGHTSHIP

TEXT-FIG. 15.—Charts showing the maximal quantities of *Ceratium fusus* in numbers per mile (scale inset) recorded in each of the years 1935, 1936 and 1937 at different points along the three lines together with a chart combining the three years.

unusual, it still played a similar part in the autumn and dominated the patches of the east, giving rise to a definite secondary maximum.

Although detailed analyses are not available, reference to Plate XI shows that there could have been no important easterly patches of *C. fusus* in the spring of 1933 since the whole group was scarce there ; from 1934 onwards these have been increasingly important. Again, its importance could only have been slight in the autumn of 1933, and it was relatively slight in the autumn of 1936. On the whole it probably increased in numbers from 1933 onwards (appearing to be relatively scarce even in that year of low values), and the maximum was undoubtedly in 1937. For 1935–37 some of these features are shown graphically in Text-fig. 13, and we can see how the relative proportions of the furca group and *C. fusus* may be reversed during each season. There seems good reason to believe that such a change occurred from 1932–34 also. In Text-figs. 14 and 15 the maxima are shown for these forms and the relationships are seen also in their spatial aspect, the furca group being dominant each year over the western sector and *C. fusus* over the eastern one. Necessarily a feature for each form includes a tendency to be relatively more abundant towards the east during the three years, perhaps emphasizing the trend noticed for the whole group.

Copenhagen Line :

We have already seen that the greatest Dinoflagellate productions on this line appear at the eastern and the western ends with variable patches in the centre. *C. fusus* (Plate XX) takes part in the formation of each of these, but as far as our records go (incomplete in the west in 1936, but supported by some detailed evidence in 1934), it plays no large part in the west until July or later, although being variably important in the east from April onwards, when the first appreciable patches appeared (*cf.* also the Bremen Line). On the other hand the furca group (Plate XIX), whilst contributing to the formation of both types of patch, is proportionately more abundant in the early part of the year, *C. fusus* increasing numerically at both ends towards the end of the year, and sometimes in the centre. It is not, however, necessarily dominant at this time, as we found it to be on B.

In these respects the three years 1935–37 have been sufficiently similar to be described together ; a somewhat similar course seems to have been followed in 1932–33 as far as the evidence goes. Differences concern the varying quantities and the primary and secondary maxima. We have suggested that *C. fusus* was scarce in 1933 on this line and probably more abundant in 1934. The year 1935 was perhaps similar, but numbers were higher in 1936, and higher still in 1937, as we see in Text-fig. 13. On the other hand, the furca group probably increased from 1933 onwards until 1936 and then was lower in 1937 (considering only that part of the line between the old termini). The remaining group of Dinoflagellates was definitely most abundant in 1937, increasing steadily from 1935 (and probably 1933). On p. 138 we saw that 1932–34 were low years as a whole, and showed a rather weak trough between the primary and secondary maxima, whilst 1935–37 were all increasingly denser and had more marked troughs, 1936 having the weakest trough. On B, *C. fusus* contributed mainly to the secondary maximum, but here we see that *furca* and *fusus* both contribute largely, although the proportion of *fusus* may be greater. Text-figs. 14 and 15 show the maxima over this line ; over all there is little difference between the distributions of the two forms, but the furca group tends to weigh a little more heavily in the west (the difference is mainly seasonal and not so clearly reflected in space as on B).

Rotterdam Line :

This line may quickly be dismissed (Plate XVI). Although not fully analysed, the tube analyses and notes make it clear that in 1935 the relatively large production was due mainly to *C. fusus*, although the more central (and earlier) patches contained more of the furca group. In 1936 totals were lower again, furca was rare and the only patches were made up mainly of *fusus*.[1] Until 1937 no patches had been seen before the early autumn, but in this year from May until the dense patches of September and October *C. fusus* was definitely dominant (almost pure patches being common) and only small patches of the furca group were to be found in September and October. Throughout the period Euceratia were remarkably scarce, although one or two patches appeared in the autumn of 1937.

Esbjerg Line :

The only complete series on this line was in 1937 (Plate XXI), and as far as these records are concerned, *C. fusus* was undoubtedly the dominant form, particularly at the southern end of the line. It thus shows general agreement with the other lines, as will be seen in the serial charts.

Distribution over the Area.

This is shown for 1935–37 in Plates LVIII to LXIV. It is not possible to give serial charts for the earlier years, but the general picture shown by the notes and tube analyses suggested the appearance at the eastern end of B of patches more or less dominated by C. furca in the early autumn of each year, information about the earlier months being less certain. From January to March, in the later years, *C. fusus* is the dominant form, small patches occurring in the east and west of B and C. The total numbers increase considerably in April, the furca group dominating sometimes (1935 and 1936) and *C. fusus* at others (1937). Somewhat similar conditions persisted into May, June and July, eastern patches on the C Line in these and earlier years often spreading to the west and consisting mainly of the furca group, as also the western patches. On the other hand, *C. fusus* has been relatively more abundant in the east and may even be dominant. Subsequently there has been the usual decrease, and this was followed in 1935[2] and 1937 by secondary maxima composed largely of *C. fusus* ; whilst this was not so clear in 1936 (no sign on B or C), the patch of *fusus* on the new E line in October (actually overlapping B) suggests that a small increase might actually have been missed then on B. Meanwhile the proportions generally of the furca group have been decreasing and those of *fusus* increasing, quite appreciable patches appearing near the Humber on both B and C and even on R. The greater numbers, however, have been mainly in the east, this being particularly marked in 1937, and in the unusual numbers found over the eastern part of R in that year. As in the whole group, the distribution in November and December is very irregular, the furca group perhaps dominant on the whole, but we may note a large patch of *fusus* on the new E line in December, 1937.

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[1] More " patches " are shown here than in Plate XV (total Dinoflagellates) ; this is due to the difference between the scales, that for Plate XVI exaggerating small patches.

[2] The patches of Dinoflagellates on B in September and October (Plate LIX, dotted line) consisted almost entirely of *C. fusus*.

The general picture, then, shows the dominance of the furca group in the west, its preliminary importance in the east and subsequent decrease in favour of *fusus*, together with the temporary appearance of the latter in the west in July, August or September. With these changes are associated the primary and secondary maxima. The annual variations are evident in Text-figs. 14 and 15 (maximal numbers), and have already been touched upon in various aspects. A particularly striking feature concerns the tendency of the furca group not only to be most abundant in the west, but to be relatively more abundant at the edges of patches which may be primarily *fusus*, and apparently well separated from primarily furca patches.

This picture is in general accord with that of Jorgensen (1910) reviewing the distribution of the Ceratia during the years 1902–08. He found both forms to be common in the North Sea, entering from the North between Shetland and Norway ; *C. furca* is suggested to have an autumnal maximum in the area and *C. fusus* one in late autumn, but as far as our material goes we have to conclude that furca had a summer maximum and that *fusus* has relatively smaller numbers in the summer, its true maximum probably extending into the early autumn. Whilst the former is said to be rarer in the English Channel (and consequently rarely enters the North Sea from there) the latter is more common and, according to Jorgensen (p. 217), "kann aber anscheinand in gewissen Jahren durch reichliche Vermehrung der Art in der südwestlichen Nordsee den Bestand der Nordsee wesentlich vergrossern". It is possible that the findings on the Rotterdam and the Esbjerg Lines may be taken as related to the variable pressure of Channel water, but this is a complex matter, and must be deferred for discussion in a subsequent paper. However this may be, the remarkable variations in the stock of *C. fusus* in the Southern Bight should indicate changes during the period in which 1935 and to a much greater extent 1937, differ from the other years.

It is on the basis of these preliminary results that we feel that more detailed study of the Ceratia may provide useful evidence of long-period changes, and also suitable indications of differences between water masses. Gran (1902, 1912) has stressed the latter aspect, although not in reference to these particular species, whilst Frost (1938) has presented some evidence from Newfoundland waters regarding six species and the associated water temperatures. Of these *C. fusus* is suggested to have a strong Atlantic water preference, although as the contrasts are between Atlantic and Arctic water in that area, such a preference need not be applicable to the present region. *C. macroceros* and *C. tripos* are found generally to indicate warmer conditions than those for *C. fusus*, and *C. longipes* colder conditions. If correlations of this type can be established and extended during the coming survey it may be that, with limitations, phytoplankton results could be extensively used to supplement hydrological evidence obtained by other means. Such correlations could provide broad indications of marked differences, whilst the material just reviewed for *C. fusus* and the furca group suggests that more subtle differences might be determined by detailed reference to their very closely associated distribution (the changing proportions of the two species at the edges of patches is referred to here).[1]

PHAEOCYSTIS.

The analysis of this form has presented peculiar problems in this work. The pressure which it undergoes whilst on the large spool of the recorder results in the colonies becoming quite coalesced and inseparable, appearing as a more or less homogeneous jelly containing a variable proportion of algal cells (and, of course, other forms if present). This has prevented any certain specific identification, although it is probable that by far the greater part, if not all, of the Phaeocystis has consisted of *P. globosa*. A secondary difficulty has been that of distinguishing the thin film of Phaeocystis when catches are low from other common scums and films which also may contain similar but unidentifiable algal cells. Further, it has only been possible to estimate the quantities of Phaeocystis by measurement of the volume after scraping off the silk and settling for periods in standard tubes. This last is clearly unsatisfactory in many ways, of which the most important may be that there is some inevitable (and perhaps variable) loss due to the scraping process, and that this will be a larger percentage when the quantities are low. Further, it is not possible to separate Phaeocystis from the other organisms in the samples, and so the values are necessarily inclusive of the volumes of these. Since it is not often that other organisms are abundant in the presence of dense patches of the flagellate this weighting is less serious than it might be. The most serious effect of these disadvantages arises when volumes are low—that is, the time when identification is most doubtful. In view of this we have set a lower limit, and only patches attaining this limit have been included, even for the sake of consistency, excluding some undoubted patches which only attain values below this figure. All forms of collecting apparatus have a threshold value below which they will not indicate satisfactory forms which are still definitely present. With the recorder this threshold is higher than with most of the more usual samplers, and in the case of Phaeocystis it has been felt that in order to avoid the more doubtful samples it would be quite justifiable to raise this limit slightly.

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[1] The results for 1938–39 already suggest that this may not be too optimistic a view.

The values obtained in this way form the basis of the distribution graphs and, as a result of this particular method, it has been possible in some respects to retain more consistency throughout the survey than holds for the diatoms. The chief difference concerns the process of recording in longer units (10-mile blocks) during the last two years. The adoption of the threshold volume leads to the inclusion of samples having lower volumes *per mile* in 1936 and 1937 than in 1932–35, and so apparently more extensive patches may be the result. Another effect of this alteration has led to the type of smoothing referred to elsewhere. Dense patches of small area which would have appeared as such in the earlier years cannot appear so in 1936 and 1937 (*e.g.* a patch providing a volume of 20 c.c. and extending over 2 miles would have been recorded as such in the earlier part of the survey, but in later years must appear as 20 c.c. over not less than 10 miles—a definitive 10 c.c. per mile for 2 miles, as against an apparent 2 c.c. per mile for 10 miles). It is clear that the data have gone through an averaging process, and we must guard against this in assessing the relative productions.

Bremen Line :

The distribution is shown in Plates XI and XII with that of the Dinoflagellates, Phaeocystis being indicated by the broken line. The major patches have been most common in May and June, although a few large ones and some smaller ones have appeared at other times. In this and some other respects there have been similarities between the years, but there are also well-marked differences. On the whole there has been a tendency for much of the development to take place in the east, but this can only be described as the major region in 1932, 1933 and 1937, there being a strong central and even some western growth in 1934–35 and a mainly western element in 1936. There have also been variations in dates of appearance, although as yet these do not seem to call for particular comment. Owing to the problems concerning small quantities, which may yet be appreciable in total quantity over an area, the usual graphs of record totals will not be shown, but there are significant differences, the years 1933–34 and 1937 being probably years of larger production than 1935 and 1936. This difference may be seen in Text-figs. 16 and 16*a*, where the maximal quantities found on all parts of the line have been plotted for each year.

Rotterdam Line :

The distribution is seen in Plate XV (broken line). As on the Bremen Line the maximal patches have been found in the spring, and there have been no significant growths during the whole of this survey outside the period March–August. The maxima have usually been found over the eastern half or third of the line.

and in 1932–34 they were limited to this, but whilst in 1935–37 the patches each year began in that region, by June they had spread over to the western coast, the densest areas in the last two years having changed from east to west. There do not seem to have been any striking variations in quantity with the possible exception of the year 1934, in which there was no growth before May (and possibly June), and when only very small quantities were found after the incompletely sampled month of June ; this was also the only year in which samples were obtained in August. The general annual distribution is shown in Text-figs. 16 and 16*a*.

Copenhagen Line :

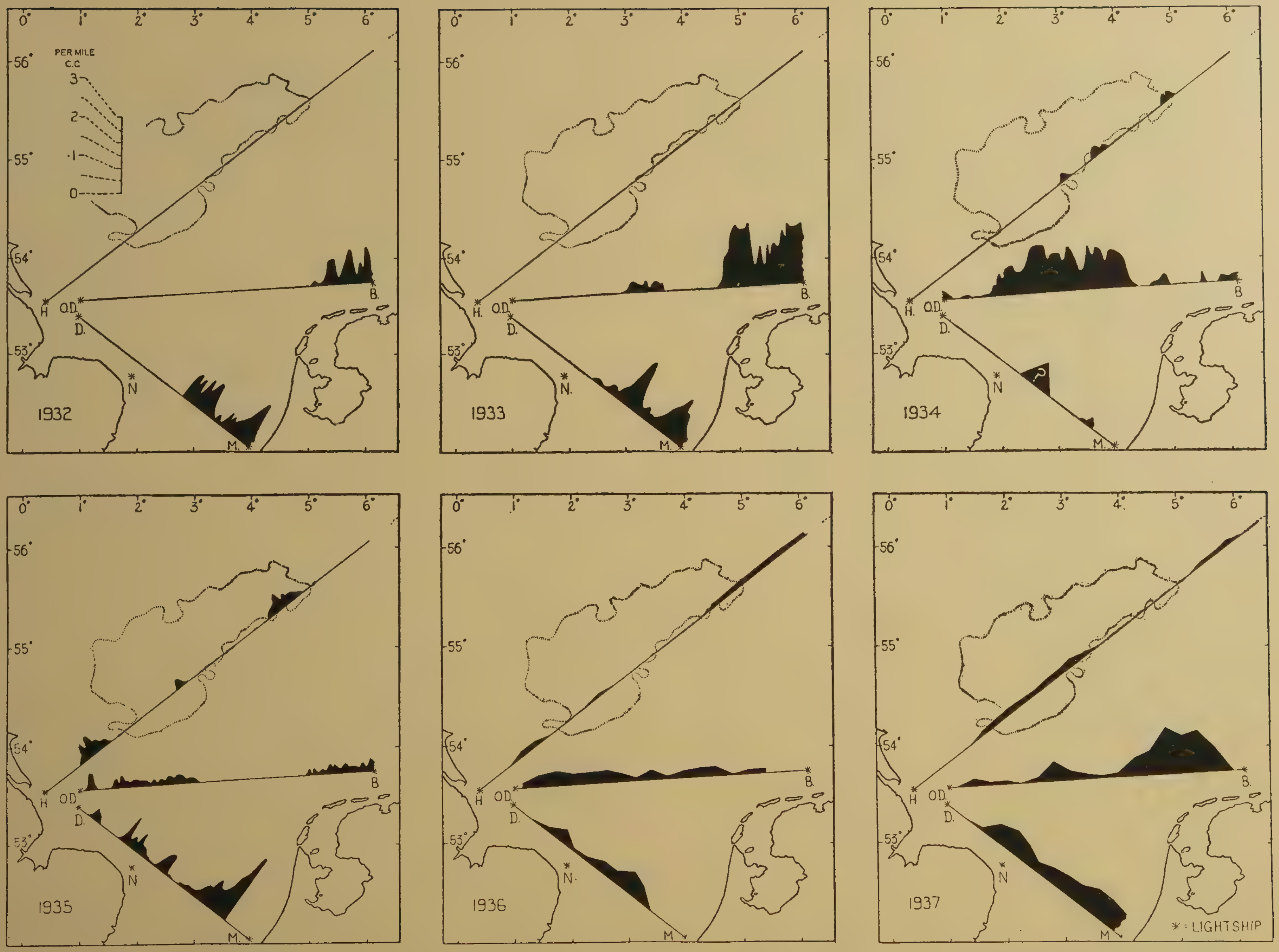
The distribution is shown in Plates XIII and XIV (broken line). No patches were found in 1932 and 1933, and only very small ones in March, April and December, 1934 (the latter is the only occurrence we have for that month). They have been more extensive in the later years (April–July in 1935, at least June and July in 1936, and April–June and August–September in 1937), but even then the densities and extensions in space have been much below those found on lines B and R. Undoubtedly the greatest quantity was found in 1937 (even allowing for the possible distortions caused by the inclusion of smaller amounts per mile).

Esbjerg Line :

No records were obtained in 1936 after March, and no Phaeocystis was found. The results for 1937 appear in Plate X ; it was widespread in May and June, and small patches occurred at the end of July.

Distribution over the Area.

This is seen in Plates XLV to LVII along with that for the Total Dinoflagellates (Phaeocystis shown by the broken line). Whilst these charts reinforce the general conclusions that the greatest bulk has been found in the east, the exceptions are similarly obvious and can easily be compared on the different lines. In particular it now becomes clear that each year (except 1934) eastern patches are among the first to appear, and that later there has been a variable tendency for patches to appear centrally or in the west and the north. The latter may never have occurred in 1932 (we have no information before June, when patches were definitely over the eastern ends of B and R), and in 1933 there was only a slight central extension over B and R in June, the last samples being found in the east again. Both central and northern (C) patches were found in 1934, and in contrast to the previous years patches extended up to the Outer Dowsing Light. The westerly elements dominated on the whole in 1935 and 1936, but although they were still evident in 1937 the strong eastern patch on B is a dominant feature.


0°
1°
2°
3°
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PER MILE
C.C
3
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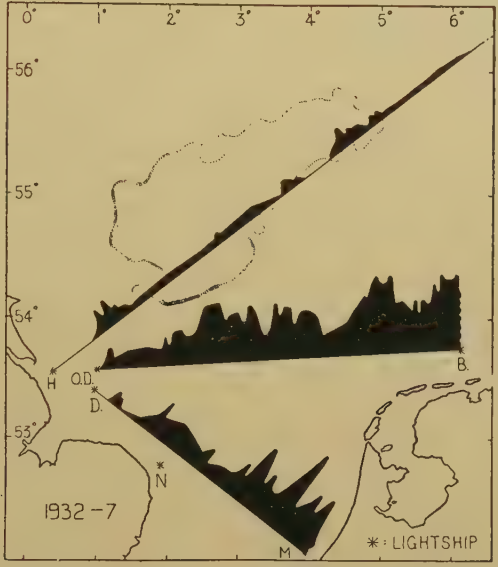
0
H
O.D.
D.
B.
N
M.
?
1932
1933
1934
1935
1936
1937
*: LIGHTSHIP

Text-fig. 16.—Charts showing the maximal quantities of Phaeocystis in volumes of c.c. per mile (scale inset) recorded in each year at different points along the three lines. Note that 1932 was incompletely sampled. The "patch" on the R. line in 1934 (labelled " ? ") may have extended further to the East.

Northerly patches were found in all these three years, and in the last even extend up to September.

As with the other forms, the differences may be at least as evident as the similarities. For spatial distribution both are summarized in Text-figs. 16 and 16*a*, showing the maximal annual distributions along each line; they present a general estimate of the quantitative variation over the whole area, and it is evident that we can broadly distinguish the years 1932–34 and 1937 as being dense years, and 1935–36 as being less dense. Other differences concern the general time distributions; although the dense patches have commonly occurred in the spring there have also been small ones in the late summer and autumn, the most extensive being those found in September on C in 1937. Both the spring and the autumn patches are in agreement with the findings of previous surveys in these waters (*cf.* Ostenfeld for a résumé, and Savage and Hardy, 1935, with Savage and Wimpenny, 1936, for some detailed surveys; also Wulff, 1934). The last two of these papers provide actual data for comparison with our records, and in such instances there has been a substantial agreement between results from the two methods, although at times small patches have been found, *e. g.* in the region of the Copenhagen Line and in the south in the autumn, for which we can show little or no data in Plates XLV to LVII. It seems clear that such differences must be due to the very much higher threshold value of the recorder, the quantities at these times being below the lower limits which can be attained.



Text-fig. 16a.—Charts showing the maximal quantities of Phaeocystis in volumes of c.c. per mile recorded on the period June, 1932–December, 1937, at different points along the three lines. The separate year charts in Text-fig. 16 are here combined.

General Discussion.

Professor Hardy has outlined in 'Bulletin' No. 1 the plan on which we are hoping to produce the results of this and the extended surveys. The object is to further the understanding of the North Sea as a whole while relating our conclusions to the broad problems of the fisheries, ecology and meteorology. Although it is convenient to produce the bulk of the data in the rather water-tight compartments of phytoplankton, Copepoda, etc., which we have adopted, it will be necessary later to assess these in relation to the entire plankton community, as far as is possible, and so discussion in this paper will only be brief, and must be limited to outlining some of the more obvious conclusions from the phytoplankton data alone.

Patchiness in the Phytoplankton.

Since early in the history of pelagic ecology there has been discussion regarding the regularity of distribution of life in both the oceans and in more coastal waters. Some of the evidence has recently been reviewed by Hardy (1936*b*), who has demonstrated clearly that the oceanic plankton may at times be very patchy. Hensen's hypothesis of even distribution, at any rate in regard to coastal waters, has been more or less rejected for a long time but, although irregularity has been recognized, its existence has not been fully acted upon, and investigation still proceeds, to some extent perforce, *as if* distribution were largely regular (biologically and physically). With the finances available it would rarely be feasible for research ships regularly to cover large proportions of even the North Sea, and yet to take samples less than some 30 to 50 miles apart; the more intensive one survey may be, the longer the time likely to elapse before another may be undertaken. As a result there is a tendency to take samples in order to ascertain variation over the area, and then to assume regular distribution between the stations for the purpose of producing contour lines and a resultant picture of the distribution.

Interpolation, and even occasional extrapolation, are adopted in the process of contouring, and it is important to realize the limitations of the methods, and to have some information concerning the probability that the assumed distribution between a pair or more of stations will be sufficiently like the real one. Workers on a small scale have at times found considerable differences between adjacent stations, Herdman (1923), for instance, finding much greater variation between the catches of similar nets (towed at the same time on either side of the ship) than could have been caused by the errors of random sampling in analysis. Hardy and Gunther (1935) and Hardy (1936*b*) found similar variations between consecutive samples in Antarctic waters, whilst almost any record taken during the period of abundance of any form during this survey shows similar or more pronounced irregularity, varying according to the conditions. The records may thus provide a means of comparing theoretical distributions with certain actual conditions in the sea—a process which may not only be applicable to immediate pelagic problems, but which could, with suitable arrangements, provide the very necessary checks upon certain principles generally assumed to apply to population studies.

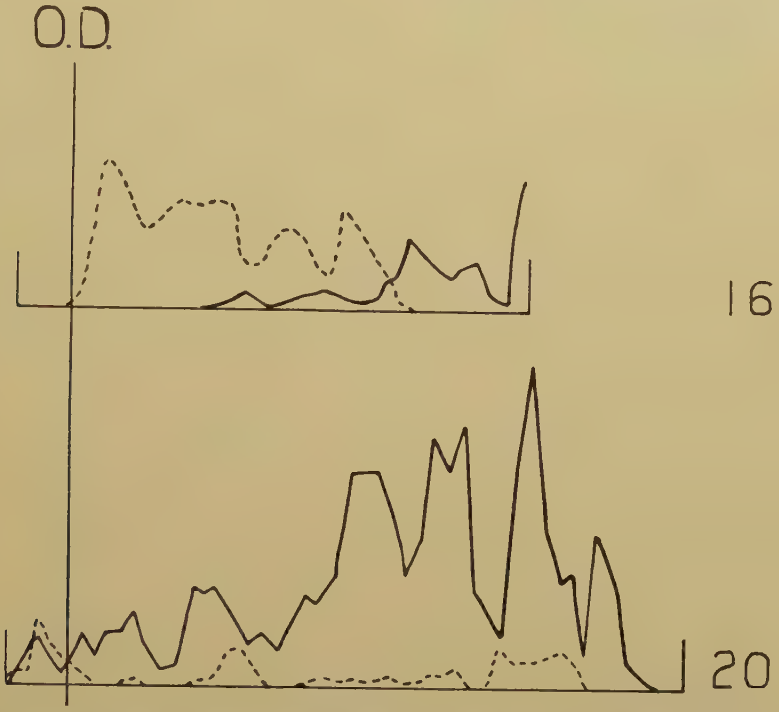
In considering patchiness a word is necessary regarding the accuracy of recorder analyses. It has been explained that the graphs have been produced without any smoothing of irregularities (apart from the automatic action of the recorder discussed in ‘ Bulletin ’ No. 1) ; the immediate data from the analyses have been used and, as in any other process involving subsampling, there are probable errors which arise from that process. Such possible variations must discount to a large extent the smaller irregularities found in the graphs, but apart from these there remain much more significant variations which we may truly describe as showing “ patchiness ”. Typical are the dense and extensive patches of *R. styliformis* in the autumn, those of *B. sinensis*, and the large patches of Dinoflagellates ; in addition there are the smaller but still dense patches of these and other forms which occur from time to time (*e. g.* the eastern patch of *R. styliformis* in October, 1935, on the B line, and the patch of Dinoflagellates at the western end of the C line at the same time). Of these, the former would undoubtedly be revealed by the usual methods of plankton survey (as the patches of Rhizosolenia and Biddulphia have been found), but the latter would not so likely be found, since their small extent places them within the usual distance separating adjacent stations on a survey. Similarly, although the more extensive patches would probably be found, it is less likely that their boundaries would be determined with any precision and, as we may see from a large number of Rhizosolenia patches, either or both of their boundaries may be very abrupt. It is this type of abrupt rise and fall in the population which is the important feature of patchiness. I have discussed at some length on p. 83 the relation between a continuous series of samples obtained with the recorder and the impression received from graphs of every tenth sample, by reference to an actual record including such sharp variations. It was seen that a very different picture might be found if samples were even as little as 15 miles apart, and clearly there is greater chance of being misled when the distances are larger. The series of examples shown in Text-figs. 1 and 2 will also demonstrate that no usual system of interpolation could have deduced the real conditions from some of the possible alternatives when the samples were more than a minimal distance apart.

There should be little need to stress the importance of such variations ; they suggest sharp changes in the hydrological conditions in most instances, and would be of even greater interest if this were not the explanation. This being so, there seems reason to qualify to some extent the picture produced by contouring between a set of scattered observations. The individual samples have their own undoubted value, but the contours may provide a picture (even apart from the unjustifiable process of extrapolation) which may be ambiguous or even erroneous. The recorder surveys demonstrate the existence and extent of such variations, and there can be little double that at least some of the divergences between these results and others at the same time in the area have arisen from such factors.

It is unlikely that the limit of patchiness is shown in the graphs: in 'Bulletin' No. 1 Professor Hardy has disscussed the "smoothing" action of the recorder, through which there is no doubt that the more abrupt changes have been levelled to some extent. Mechanical "clogging", which has undoubtedly taken place when the plankton was very abundant, will have had a similar effect. The former process will be more effective in the graphs for the years 1936–37, when the treatment of the data in blocks of 10 miles must have masked any of the particularly high peaks which might have occurred. Comparison of these with those for 1932–35 will show that, although sometimes higher numbers were found in the later years, yet during these years no patches appeared similar to that of the Dinoflagellates in 1934, for example; similarly the autumnal patches of *R. styliformis* have not in these years shown such abrupt changes near the Outer Dowsing Light-vessel as were a feature of 1932–35. These changes often occurred within less than ten miles, and on the new system would be more or less smoothed and the slope of the graph would become more gradual. In changing the method we realized that some sacrifice of precision must be made for the purposes of spatial extension, *but the results still are continuous records*, taking in all the data, although giving "smoothed" values at greater intervals.

In the forms which have been more fully discussed in this report the smaller dense patches have usually been at least some 10 miles in extent, and the rapid changes at the edges of patches have often occupied some 3 or 4 miles, but Herdman has referred to patchiness over smaller distances than this, and it is not of purely academic interest to wonder what are the lower limits of patchiness. Whilst our data shows that often the edges of patches may occupy the space of a few miles, at times this has been much less, and during the earlier part of the survey we have often noticed the abrupt change on the recorder silk as occupying only a fraction of the section—and so presumably occurring within a distance of not more than one mile and probably less. For certain purposes there would appear to be good reason for investigating further the details of patch boundaries by means of a recorder working at a ratio of, say, ten sections per mile, or even more. In this general connection we may note that Helland Hansen (1910) saw reasons to believe that the usual distance between hydrological stations was by no means satisfactory, and often misleading, for the important purposes of determining the edges of different water masses, and his earlier work, together with the recent results from the Bergen school (*e. g.* Eggvin, 1937) provide ample justification for such a view. Such results, together with information regarding the plankton, point strongly to the necessity of obtaining hydrological data at much closer intervals if certain types of "water change" are to be adequately understood.

Helland Hansen and also Herdman likewise postulated the probability of sharp changes in time, both providing some evidence of this. The close association between certain changes in space and time in pelagic ecology has already been stressed elsewhere (Lucas, 1936 and 1938), and there is little doubt that some of their examples concerned temporal changes which, seen from another aspect, would have appeared as spatial variation. It is clear that certain changes observable in the sea at intervals of a week or less might also be seen during one day by an observer moving from place " a " to take samples at " b ", which, under the influence of currents, will be due to replace " a " within a few days. On the other hand, there will undoubtedly be other changes due to the growth or death of the plankton or to physical mixing of the water, which cannot be seen in both ways. However this may be, there are undoubtedly marked changes in time in these records as well as changes in space. A particular one is shown here in Text-fig. 17, the interval between these two records being sufficiently small to render the two records confusing when superimposed in their correct places in the compound graph for 1934. The Dinoflagellates are seen to have increased very much during the four days, and the Phaeocystis patch has almost entirely disappeared. Other examples will be seen in the various graphs, and will at once illustrate the rapidity with which the picture may be changed during a short interval, and also some defects



Text-fig. 17.—Graphs of total Dinoflagellates (continuous line) and Phaeocystis (broken line) for the Bremen line on 16th and 20th June, 1934, showing changes of distribution in this short period. The former record was incomplete at its eastern end. The vertical line marked O.D. denotes the position of the Outer Dowsing light vessel. The scale is proportionately as that in Plate XI, which also shows the second graph; this actually extended further to the east than is shown in this figure.

in both the present and the more usual methods of survey. In so far as such changes are temporo-spatial, then the type of patchiness which the recorder reveals along its line of travel may, along another axis, be the cause of rapid change in that picture ; on the other hand, when these changes are more truly temporal the orthodox methods suffer in that their surveys are necessarily at relatively large intervals of time. (For example, the appearance of primary and secondary peaks in the Dinoflagellate maxima in this area reveals a type of temporal change, not over a very short period, which would not be likely to be revealed by the customary quarterly surveys.) Such considerations should also weigh heavily in assessing the evidence of larger surveys, in which necessarily an appreciable time-lag occurs between the first and the last station. Particularly if the stations are not taken in consecutive spatial order, temporal changes may produce great deviations from actuality between adjacent stations. Except for very good reasons an attempt should be made in all such surveys to obtain *adjacent* stations with the least possible delay, and even then due allowance should be made, as Kunne has pointed out (1937), for the time interval between the first and the last. Such changes emphasize the essentially dynamic nature of pelagic ecology (perhaps seen more clearly than in terrestrial ecology), and, in particular, the danger of drawing conclusions too extensively from the values of isolated surveys for certain comparative purposes.

Usually we find that there are one, two or three major patches on the combined graphs for any one month ; this in itself may be a feature of interest, but it suggests another aspect of patchiness which may in the future be worthy of investigation. With the data available it should be possible to obtain correlations between the density and extent of patches and, in the case of some which seem to be annual features in this area (*e. g.* the annual patches of Rhizosolenia), such measurements should give standards of variation from year to year. Rather similar statistical investigation of patches should over a long period provide information for determining under what circumstances interpolation might be justified. Except in so far as some broad characters of patches in different years have been used here, such an intensive investigation of patchiness must be reserved for a later paper which can assess the subject for other planktonts as well. Here we can merely insist on the reality of patchiness for all forms (see also ‘ Bulletin ’ No. 4) which have been dealt with, and its importance in plankton ecology. Later also it may be possible to devote some discussion to the causes of patchiness. Some will immediately suggest themselves—the natural growth from a “ seeding ” in a suitable locality, physical processes such as have been suggested by a number of writers (the suggestions of Helland Hansen would have application here), available supplies of food salts, etc.—but in addition there are biological effects which have been suggested to be important in the formation of aggregations of organisms (Allee, 1931 and 1934, and Lucas, 1938). Continuous records may throw further light on these matters.

Inter-relationships in the Phytoplankton.

When the recorder surveys were begun it was hoped that the method would provide a suitable means for attacking broad problems of ecology on a large scale, as well as problems of more immediate importance. One of the more interesting problems in the sea, as elsewhere, concerns the relationships between the organisms themselves in so far as, for the purpose of analysis, we try to distinguish such organic relationships from the " organism-environment " complex in the widest sense (see Lucas, 1938). The continuous records provide a series of correlations between "isolates" of this complex, and although these have not been investigated in detail as yet, certain correlations may be pointed out which will illustrate some possibilities of such work. Here it will not be possible to attempt a separation or analysis between the different factors—this could only be done satisfactorily by reference to detailed hydrological evidence in conjunction with the evidence to be produced in later Bulletins—and only general indications of positive or negative correlations will be made.

Reference to Plates I to X and Text-figs. 3 and 4 remind one that *R. styliformis* and *B. sinensis*, although occurring in the same season, are only for a short time during their annual cycle found together in appreciable numbers. Patches may often be side by side, but only during the Octobers of some years has typical " mixing " taken place; from these and other findings in this area there is very good reason to believe that this mixing is the result of a physical process as distinct from a " growing together ". It is clear that immediately we are face to face with the problem of the causation of such correlations, and the type of problem illustrated here—how far the usual separation of these forms in space is due to any direct relationships between them, or to more physical factors, how far they are at times brought into association by physical factors and what reciprocal effects may result, if any—are ones to which continuous records may provide a partial solution.

If now the graphs of Phaeocystis and the Dinoflagellates are considered we shall again notice negative association as the rule. However, although Phaeocystis and the diatoms referred to above are seldom associated, there may be associations between Phaeocystis and the other diatoms, as also between these and the Dinoflagellates, which can be seen by comparison of Plates XXXVII to XLIV and XLV to LVII. On p. 148 I have referred to the association between *C. fusus* and *C. furca* (the latter often being relatively more abundant on the western edges of patches of the former), and have suggested that this association might arise from slight hydrological differences, but we must also bear in mind that this might also appear from some more biological relationship between the two. Careful comparison between the graphs for *R. styliformis* and *C. fusus* will show from time to time a somewhat similar correlation between these, and there are numerous other examples concerning the different groups of the phytoplankton. Whether these features are the result of hydrological influence or of more specific inter-relationships, they are features which may likely repay further investigation in the phytoplankton and in the other groups.

These have all been relationships in space, but as has long been observed, there are time sequences in the production of different forms (*e. g.* spring diatoms, Phaeocystis, Dinoflagellates, summer diatoms and the autumnal forms such as *R. styliformis* and *B. sinensis*), and these present another aspect of inter-relationship which may not be unconnected with the former, and will form the subject of future investigation.

Movements in the Area.

In spite of certain limitations in this method of survey it has still been possible to obtain more or less detailed information about the movements of the larger patches of phytoplankton at certain times of the year, and particularly in the autumns since 1933, when on some of the lines fortnightly and weekly samples have been taken. The introduction in 1936 of the E line, which crosses both R and B, has further aided in such work, as also did the extension of B and C in the latter half of 1937. Apart from the obvious benefits of increasing the number of the lines, much greater aid can be obtained from those which intersect others or run in other directions. The extension of the survey in 1938, in addition to providing merely more data, has already shown that a network of lines should enable this side of the work to develop further.

Savage and Hardy (1935) referred to the complementary evidence to be obtained from both records and tow-net samples, and from these they suggested an overall north-easterly drift of the Rhizosolenia complex in 1932 round the southern edge of the Dogger Bank. Somewhat similar movements have been found by us in later years when the greater number of records made more detailed deductions possible. The general trend suggests the now familiar appearance of patches of *R. styliformis* in the region of the south-west patch, their growth and more or less gradual movement in that region and, mainly later, an apparent drift to the north and east. Associated with this we have found the patches of *B. sinensis* appearing variously in the south and east of the area (Flemish coast, Dutch Islands and German Bight), developing, and also appearing to move north and north-eastwards, the bulk of both forms being usually found later over the centre and eastern parts of line C respectively. There are striking detailed differences from time to time, and without attempting to justify the suggested connections between the patches, reference to Plates XXII to XXXVI may support some of these. Often we see *B. sinensis* appearing earlier on B and R than on C, and it is suggested that the later patches on the latter may be in part due to a northerly movement. Typically these patches have been more than 200 miles from the Humber Light-vessel, but in 1933 the patch was only some 150 miles distant, and in 1937 patches extended very much closer still. Whilst they may have been of the same type, movements at these times in 1933 and 1937 must have differed from those of other years, and it may be also significant of variation in the current systems that such patches appeared on C in December in 1932–33, but in September or October from 1934–37. Similarly there was a more marked segregation of the patches of *R. styliformis* and *B. sinensis* from 1932–34, whilst from 1935–37 fairly extensive mixing occurred at some stage of their autumnal development. Perhaps in association with this we can think of the progressive approximation of the western edge of the Biddulphia patch to the Outer Dowsing Light-vessel from 1932 to 1937 (with the exception of 1936, which showed some recession). Numbers of other differences will show that, for all the general similarities, the conditions of each year are quite peculiarly determined, and although such analyses are most easy in the autumn, similar deviations can be made out for other parts of the year.

It will be seen how the movements of patches of *C. fusus*, *e. g.* in 1937, must have differed from those of other years. Similarly the variations in the annual distributions of certain forms must indicate important variations in movement; we may recall, for example, the generally central position of the Dinoflagellates in 1932–34, their westerly position in 1935, and the eastern one in 1937, whilst the apparent stability of conditions in 1935 (the maintenance of patches of various forms in similar places for long periods) further distinguishes it from some of the others.

Knowledge regarding the movements in the North Sea has gradually advanced, the earlier work of Fulton and Böhnecke (to mention only two) being extended by the more detailed surveys of Tait and Carruthers. Even now the picture tends too much to be a static one, as both writers have emphasized, although in this particular area the continuous current measurements at certain light-vessels (*e. g.* Carruthers, 1935) are gradually building up a set of standards and temporary deviations from them which are valuable in understanding more fully the generalized picture now available. It is, we hope, with a full appreciation of the limitations of the present work that it is suggested that a series of continuous records of the plankton may also give data which, apart from its intrinsic value for ecology, may help to supplement the hydrological and hydrographical information which is being produced. Cleve, who first tried to follow the movements of the plankton, was shown to be wrong in many of his premises, but more recently there has been a return to a modified version of Cleve's ideas in which more attention has been paid to the life-histories and habits of the "indicators" (*e. g.* Russell, 1935). Whilst in some ways the macroplankton species are more valuable as indicators (see, *e. g.*, Russell, 1936, and Kunne, 1937), it is felt that a satisfactory method of following the life-histories of major phytoplankton "bodies" (*i. e.* characteristic long-lived patches such as those of *R. styliformis* in 1935 and 1937, *C. fusus* in 1937, and such complexes of other diatoms which have been found to persist for some period) may have a similar value. On the other hand, the very variability of the phytoplankton species can, if the necessary limitations be allowed for, be used to distinguish between different water masses and to delimit their boundaries with precision.

Even at this stage of the recorder survey there is evidence that it may provide such a method, and as the surveys develop more precise data may be produced.

This subject can more satisfactorily be reviewed in reference to the data for various other groups of plankton, and will later be dealt with in a paper by Mr. K. M. Rae and the present writer, dealing with the whole of the material for 1932–37 in relation to hydrological conditions.

In association with water movements we may also consider the phytoplankton in relation to the floor of the sea. Its importance to the benthic fauna and ultimately to the commercial fishes makes this the more important, and this side of the work will also be reviewed later. Here brief reference may be made to the significance of the patches of phytoplankton found so regularly over the south-west edge of the Dogger Bank, and particularly to the variations which they undergo. Other centres are apparent, whilst certain areas are more often barren, although at times a more extensive flora is found over them (*e. g.* the western end of the Rotterdam Line). These features and their variations are not likely to be without their effect on the bottom fauna and the stocks of fish.

Annual Variations in the Area.

The general trend of development of the various forms has been reviewed separately in the preceding pages. The cycle as a whole is a familiar one, although we believe that the method of continuous recording has helped to make some details clearer and, in various ways, may extend the application of such data. Yet throughout this work one of the more interesting features has been the persistent occurrence of variations upon the central theme and their association with other changes. The determination of the main lines of annual cycles formed one of the chief objectives of the International Council's programme from 1902–08, and their investigations revealed some good and bad years for different forms, the period 1904–05 being an example. More recently the year 1921 and certain years during the period under review have also attracted attention.

Variations have been found in the occurrence of all the more abundant forms which we have been able to deal with, and they have concerned spatial distribution, apparent movements, temporal occurrence and size of maximum, etc. Clearly the methods are not ideal, and some of the apparent variations may be misleading. In the relatively short lives of some of the diatom patches, the omission of a record in any month may seriously affect the picture of its cycle, whilst within the usual period of one month between two records very extensive changes may occur in the distribution of any form. But equally clearly these are criticisms which apply, perhaps even more seriously, to some other forms of survey. We have to make such use as we can of the methods available, and when certain allowances have been made for such inherent defects in the methods, there still remain very significant changes of which there seems little doubt. An example has been raised on an earlier page regarding the occurrence of *R. styliformis* and *B. sinensis* during the earlier years of the survey. The larger gaps between the records in the autumn of 1932 and 1933 make it fairly certain that important information has been lost, and so the quantities found may be below the possible maximum, either in numbers per mile or in the extent of the patches. Nevertheless the series of records in the later years make it equally certain that large patches occurred over a longer period in these years than in 1932–33. Whether or not the actual densities attained were greater, the patches are likely to have had a more extensive influence on the area covered by the recorder lines.

By analysing the available evidence and the variable factors in the ways indicated, it is possible to reduce the apparent variations to such as should be truly significant. By no means are all the variations in the same direction, but a number of them are suggestive of a general inter-relationship and these will be reviewed briefly here :

(1) As far as our evidence goes the size and persistence of the autumnal patches of *R. styliformis* increased up to 1935, decreased in 1936, and increased again, although not to the level of 1935, in 1937. There is no doubt that the maximal density of 1934 was much less than in 1932 and 1933 ; the density in 1932 was probably lower than in 1933 and October records in 1931 suggested it to be even scarcer then. Patches were very late in 1936, and we should note the unusual occurrence of large patches in the Januaries of 1936 and 1937.

(2) Somewhat similarly the size and persistence of patches of *B. sinensis* increased up to 1935, decreased in 1936, and were even more extensive in 1937. The numbers were very low in 1932, and October records in 1931 suggest it to have been still scarcer. As with Rhizosolenia, this form was unusually late in 1936. Another aspect of the temporal changes is seen in the change of date of the first appearances of patches on the Copenhagen Line ; this was in September or October in 1934–37, but not until December in 1932 and 1933. In general, the quantitative changes were reflected on B, C and R, but a further point of interest has been the continuous approach of patches towards the Outer Dowsing Light-vessel until the western edge of patches in 1937 almost reached it.

(3) Overall the Dinoflagellates have been most abundant in the last three years ; this was most apparent on lines C and R, the appreciable patches of 1935 and the relatively enormous ones of 1937 on the latter line being striking features. Of the individual species we may note that the numbers of *C. fusus*, which were generally low up to 1935, increased greatly during the later period. A trend is also seen in the occurrence of " primary " and " secondary " maxima (see p. 139). These did not appear on C from 1932–34, but they were evident on B in 1932 and 1934, and were more marked still on both lines in 1935 and 1937. They were indistinct in 1936. In addition we may remember that whereas the Dinoflagellates were mainly central from 1932–34 and in 1936, they were more prominent in the west in 1935, and in the east in 1937.

(4) We can broadly distinguish the years 1932, 1933 and 1937 as providing

denser patches of Phaeocystis and 1934–36 as less dense on the whole, 1935 showing perhaps as the poorest. Again, in the earlier years the growths were largely limited to lines B and R in the spring, whilst 1935–37 showed increased growths on C, and in 1937 these extended into September. Whereas the early patches were mainly eastern, there were central ones in 1934, and in 1935–36 there were relatively well-developed ones in the west also. In 1937 eastern patches were again a feature.

(5) Whilst the trends mentioned above are in many respects the most reliable, those shown by the other diatoms are equally interesting and often parallel those mentioned. Overall there has been an increase in numbers since 1932, and culminating usually in 1937, although in some respects 1934 and 1936 showed themselves as being outside this trend. Some discussion has been given (p. 122) to the possibility that this effect might be due in part to improvements in the technique, but it was found that in general it must reflect a genuine increase in numbers. The increase, although large, is no larger than some others which have been observed, and is relatively less than that of the enormous changes in the numbers of *C. fusus* which were found on R, and about which no similar doubts can be expressed.

Although this increase is shown by many forms it does not appear in all, but has been most typical of Asterionella, Bacillaria, Thalassiosira, *Rhizosolenia alata* and *R. semispina* and the Chaetocerids. On the other hand, some forms have had maxima or secondary maxima in other years, *e. g. Biddulphia regia* (1933), *B. aurita* (1933 and 1936), Eucampia (1936), Naviculoids (1935), Thalassiothrix (1934), Coscinodiscus (1934) and *Rhizosolenia Stolterfothii* (1936). In association with the main trend we may note that during the period central patches on line C have become more common, and that there has been an increasing westerly element in the patches on B ; the last directs attention also to the unusual occurrence of patches over the generally barren area of the Rotterdam Line between the Dudgeon and the Newarp Light-vessels in the later years.

In review we may say that broadly there has been a progression towards greater numbers during the period under survey, although there are details qualifying this trend. In some respects a contrast can be seen between the period 1932–34 and 1935–37, but in others 1934 and 1936 may be thought to deviate from this tendency. Not all the characters have shown an increase, and those that did were not necessarily minimal in 1932, but may have had a minimum (or a maximum) in 1933. Similarly others have shown such signs of regression in 1937 (*e. g.* Phaeocystis) as to suggest some features of the earlier years.[1]

The occurrence of such a series of changes in the phytoplankton would seem to indicate some related fundamental changes in the area. Immediately one thinks of hydrological changes (*cf.* a similar comparison for the years 1931–33, Lucas, 1936), and there is reason to believe that these have been associated, but before considering this it will be instructive to compare these findings with those

[1] See also Addendum, p. 168.

of other plankton surveys. Since 1930 Russell (*e. g.* 1935, 1937, 1938) has analysed the proportions of *S. elegans* and *S. setosa* in the waters off Plymouth and has found a marked change in the constitution of the plankton ; precise values are as follows (derived from Kemp, 1938) :

	1930.	1931.	1932.	1933.	1934.	1935.	1936.	1937.
% *S. elegans* .	94·1	16·7	6·2	4·7	3·5	3·6	39·7	3·8
Numbers in thousands .	86·1	19·6	7·3	5·5	3·3	1·7	9·5	0·9
% *S. setosa* . .	5·9	83·3	93·8	95·3	96·5	96·4	60·3	96·2
Numbers in thousands .	5·4	97·7	111·0	111·9	91·2	46·5	14·5	25·2

Although only one has been stressed by Russell, there appear to be two significant features in this table. Firstly the numbers and percentage of *S. elegans* have been unusually low since 1930–31, although the numbers, and particularly the percentage, were higher again in 1936. Secondly the high numbers of *S. setosa*, attained in 1931 as *S. elegans* decreased, persisted only up to 1934, a decrease following in 1935, a minimum in 1936, and a slight increase again in 1937. In association Russell observed the numbers of several other animals (Muggiea, Cosmetira, pelagic tunicates, etc.), and found that they showed similar changes over the period. Even more important were the changes in the numbers of all young fish, which decreased tremendously from 1930 to 1937 (Russell, 1938, fig. 2). Summer spawning larvae decreased steadily from 1930–35, and then increased slightly, whilst those spawned in the spring only decreased markedly in 1935 and remained low in 1937. Russell was led to suggest that "some factor adverse to all species of fish indiscriminately" must be in operation and, showing that this was not likely to be due to the effects of commercial fishing, he put forward the suggestion that it might be in association with the parallel decrease in the phosphate content of the Channel waters (see also Cooper, 1938).

A number of these features were gathered together by Dr. Kemp at the British Association Meeting in 1938, where, in addition, he showed how the herring catches at Plymouth had decreased from 1934–35, and the percentage of young from 1931–32 (Kemp, 1938).

It seems that here are some parallels to the events which have been recorded in the North Sea. Russell (1936) has previously commented on the possible association between the decrease of *S. elegans* off Plymouth, and the increase of *R. styliformis* over the Dogger Bank as found by Savage and Hardy (1935) and Savage and Wimpenny (1936) over the period up to 1934. Whilst our findings are not in exact agreement with the latter, they also tend to confirm this suggestion and enable it to be extended ; it was not until 1936 that we noted a decrease in the general abundance of Rhizosolenia. In this year *S. elegans* was relatively more abundant, but it was scarcer again in 1937, when we found also larger numbers of *R. styliformis* over the Dogger Bank. Russell has suggested that " the two populations of Sagitta swing to and fro off Plymouth according to the strength of flow of the Atlantic water into the North Sea from the north ", and in view of what is known of such inflows in recent years it seems not unreasonable to support this view, and to suggest that the progressive increase of phytoplankton in this area is a reflection of northern pressure, and possibly arises from an *increase* of phosphates in the area. In this connection it is important to note that Cooper (1938), in discussing the changes of winter phosphate maxima at the station E1, has calculated that the production of phytoplankton in that region changed during 1933–34 to give much lower values in 1935–37, a condition almost the reverse of that found in our area.

The Reports of the Fishery Board for Scotland (1931–38) record observations of the effects of Atlantic pressure upon the northern North Sea and, as is now well known, this has shown important changes during the last few years. Briefly, there was a steady increase in Atlantic pressure from 1931 (or even 1930) until 1934 at least, this being shown by increasing temperatures and salinities (Tait, 1936). The maximum effects were attained fairly early in the year and numbers of exotic forms have been found from time to time, such as doliolids, which were also found in 1933 as far south as the latitude of Aberdeen (Lucas, 1933). Latterly there are signs that the effects are decreasing ; the maximum effects have been attained progressively later in the year, and in 1937 " the inflow of Atlantic water into the northern North Sea . . . appears to have been weaker than for at least five years ", although salinities were still above the average (Report for 1937). In association the occurrence of a large number of exotic forms in various waters during the period 1932–34 has been recorded by Stephen (1938), along with variations in annual broods during that time.

The possible relation of these trends to those already mentioned is evident ; they are clearly in some respects parallel, and it seems reasonable to look to broad changes over a wider area as the " causes " of changes in more restricted regions such as the southern North Sea. It has been suggested by Carruthers (1935) that the flow of water past the Varne Light-vessel may be the result of a buffer action between pressure from the north and that from the English Channel, which is in accord with Russell's suggestion concerning the possible relation between biological features of Plymouth waters and those of the North Sea. It is already clear that certain parallels can also be drawn between the hydrological conditions of the Varne area and the variations which we have observed in the phytoplankton cycles ; the discussion of these is reserved for a later paper dealing with relations between the whole plankton and the hydrology of these waters. Whilst it is too early yet to draw more definite conclusions, it seems likely that the changes which have been observed in the phytoplankton are at least in part related to the changes observed in the northern North Sea and to probably connected events in the Varne region. If such a relationship can be maintained, then the general increase in the phytoplankton during the period may well have been the result of an increase in the phosphate content of these waters (*cf.* also the important conclusions of Graham, 1938) arising from the unusual water movements which have been occurring both within this area and also further north, just as in the Plymouth area the reduction in Atlantic influence appears to have led to decreased phosphates, decreased phytoplankton, and an abnormal decrease in the numbers of fish larvae.

The implications of such a possibility are obvious, but it would be dangerous to speculate further at this stage, although it is hoped that some of these lines may be followed up. Meanwhile it is interesting that cycles of events with some features in common should be observed in several places in the course of different types of work. Dr. Kemp (1938), referring to the recently projected western Atlantic survey, has pointed out that this " will lose much of its value if we are unable to obtain comparable data in our own waters ". We hope that the extended recorder programme—and in particular the new Atlantic route from Pentland to the Faeroes—will not only provide data linking together events within the North Sea, but may help to link these with processes occurring further afield.

SUMMARY.

1. The changes in the composition and distribution of the plankton of the Southern North Sea have been investigated month by month from June, 1932, to December, 1937 ; the present report deals with the phytoplankton. The survey was carried out by the continuous plankton recorder, towed at a standard depth of 10 metres, by ships on regular steamship lines across the North Sea from Hull towards the Skagerrak, to Bremen and to Rotterdam, and later between London and Esbjerg.

2. The material and methods are described, together with a discussion on the validity of this type of survey and some comparison of its results with those obtained by other methods (pp. 76–86).

3. Particular attention has been paid to *Rhizosolenia styliformis* (pp. 92–107), *Biddulphia sinensis* (pp. 108–115), Phaeocystis (pp. 149–153), and the Dinoflagellates (pp. 134–149) ; of these the first three are known to be of particular importance in relation to the herring fisheries. More generalized data are available for the principal diatoms other than *R. styliformis* and *B. sinensis* (pp. 116–134).

4. The main part of the work is an ecological study of the phytoplankton changes in time and space over the $5\frac{1}{2}$ years. Each year is marked by some distinct variations in the abundance and the times of increase, maximum numbers and decline as recorded in the different forms. These variations in the annual cycles are compared on the different lines by a series of graphs arranged against a time scale of months, a set for each year being placed side by side (Plates I–XXI). More detailed studies by more frequent records were made in the autumns of 1934, 1935, 1936 and 1937 (*cf.* Figs. 3 and 4). The changes in spatial distribution are

shown by a series of monthly maps arranged in a similar manner for each year (Plates XXII–LXIV). These intensive studies of the changes in time and space are also intended to form the basis for correlations with other features in the general ecology of the area (*e. g.* the zooplankton, hydrology, meteorology and fisheries) to be made in later publications.

5. Whilst each form has shown its own peculiar features, a trend towards a general increase in the phytoplankton as a whole has been observed during the period, although the years 1934 and 1936 have in some respects shown deviations and regressive features, and not all organisms have revealed the same trend. The possible relation of this gradual trend to other events observed in recent years in these and neighbouring waters is discussed (pp. 162–167).

6. The application of these results to the study of patchiness (pp. 154–158), inter-relationships in the plankton (pp. 159–160) and to water movements (pp. 160–162) is briefly discussed.

ADDENDUM.

Since the beginning of 1938 the recorder programme has been extended to cover the whole of the North Sea and, in 1939, to include a line between Scotland and the Faroes (see 'Bulletin' No. 1). The results of the extensions are now (1940) in preparation for the press, but it may be of use to record here that during this period a number of the forms in the Southern North Sea have shown a marked tendency to return to numbers not so dissimilar from those of the earlier years. This makes it the more likely that the whole series of records has concerned a significant cycle of events in these waters, although the onset of the war may prevent conclusive demonstrations of this.

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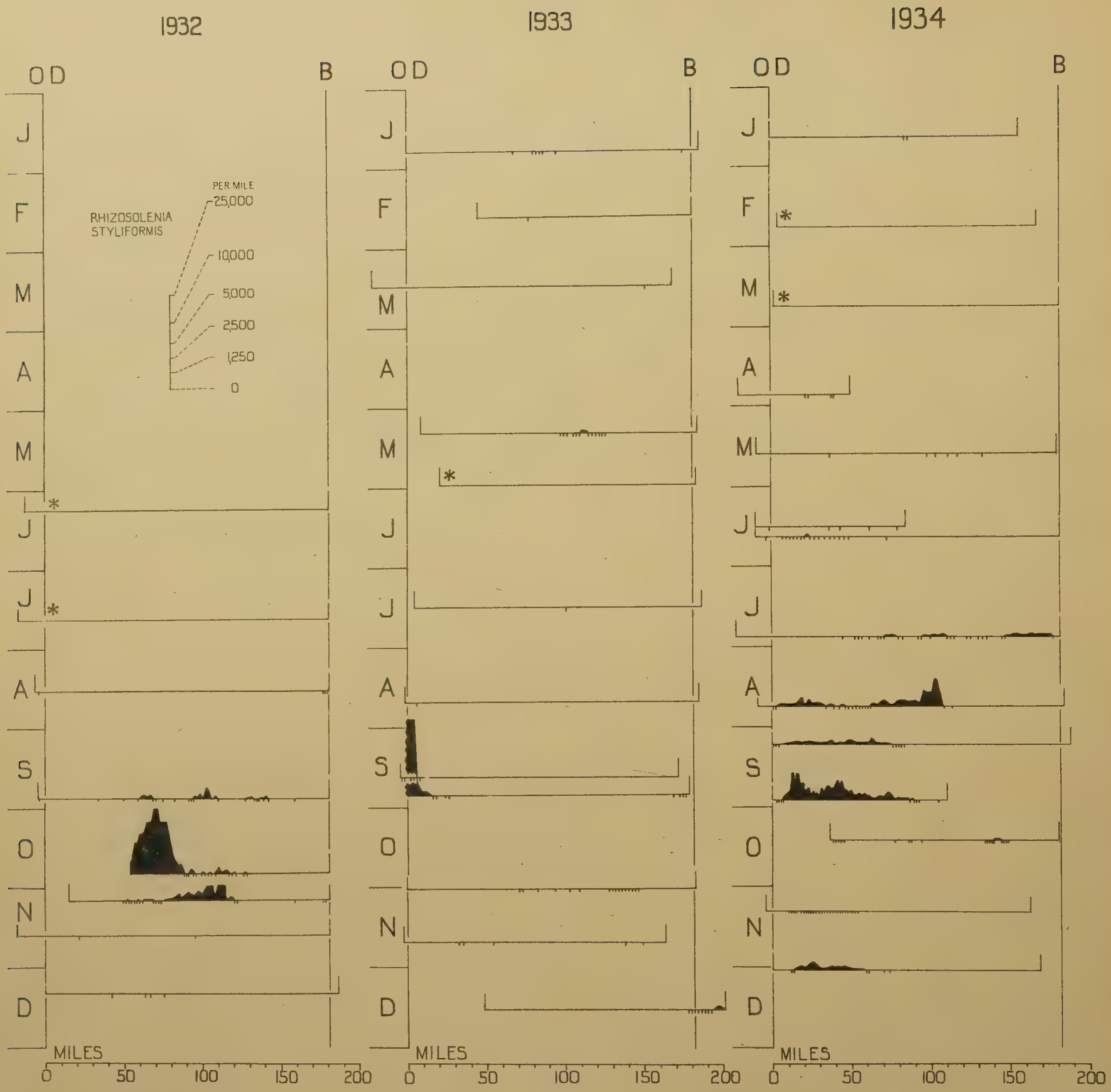
PLATES I–XXI

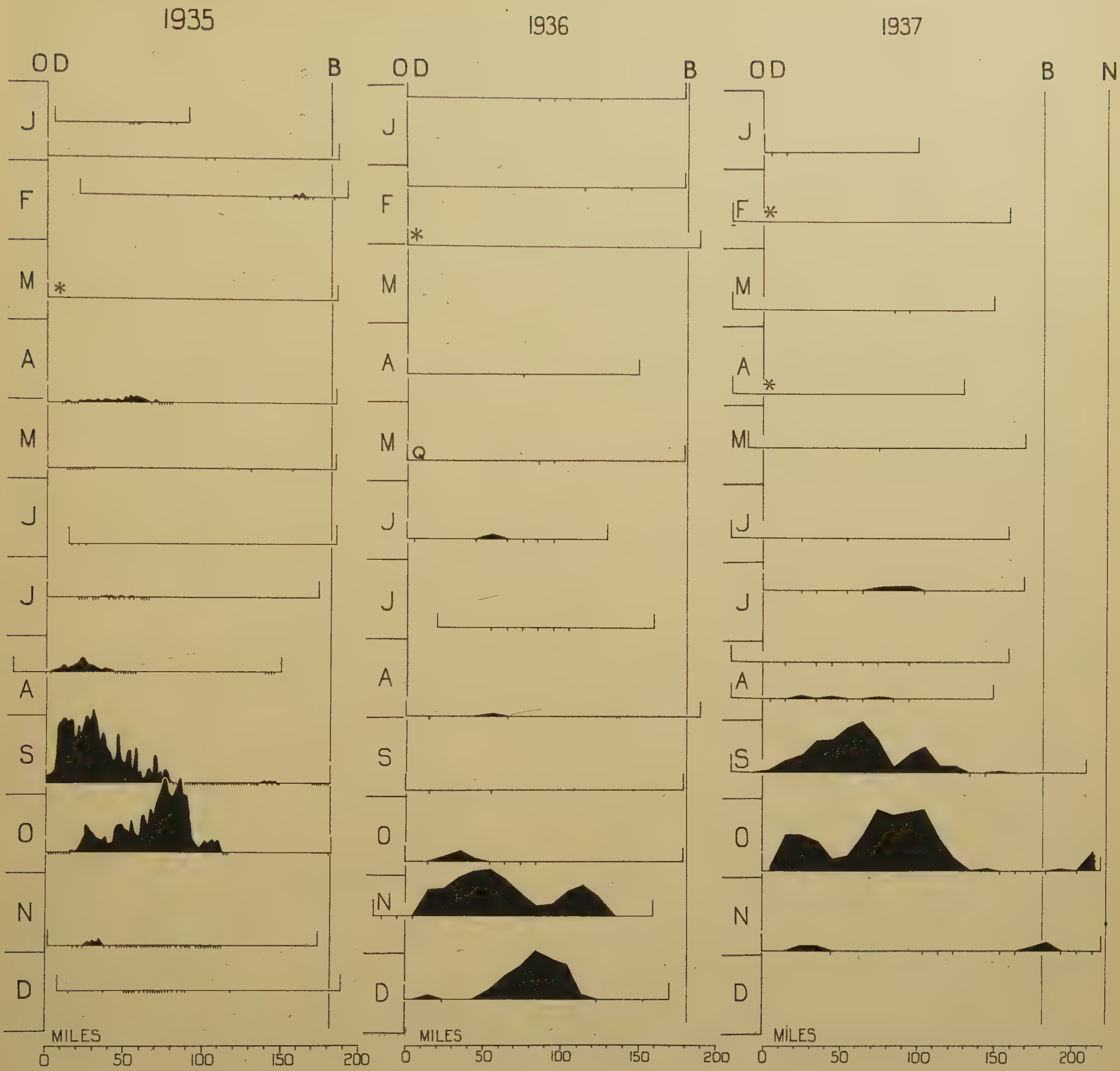
SERIAL GRAPHS COMPARING THE VARYING QUANTITIES OF THE PRINCIPAL PHYTOPLANKTON FORMS YEAR BY YEAR ON THE DIFFERENT RECORDER LINES IN THE SOUTHERN NORTH SEA JUNE 1932 TO DECEMBER 1937

PLATE I



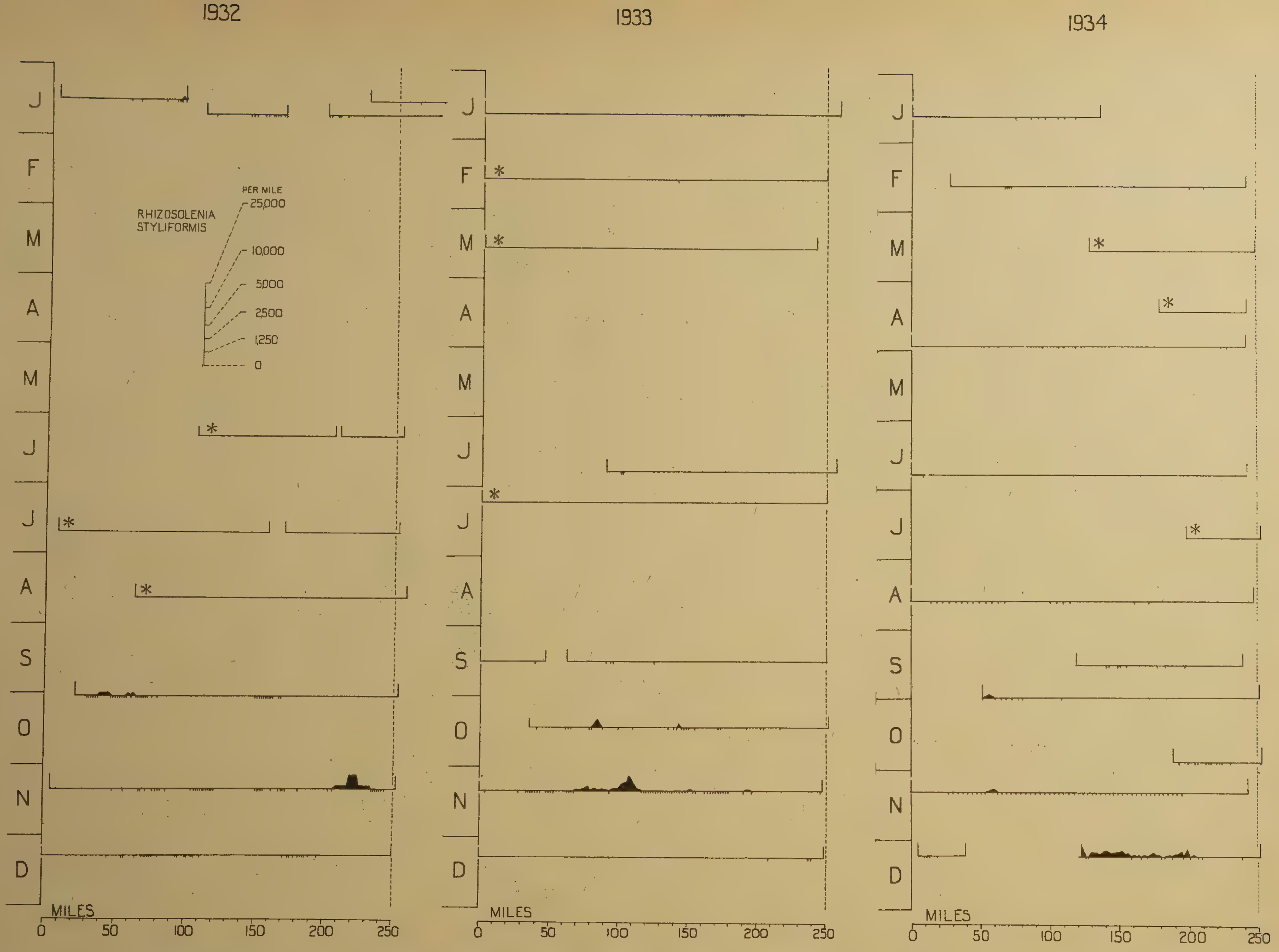
Records of **RHIZOSOLENIA STYLIFORMIS** *on the Bremen line, 1932-1934, each placed in its position of date against a vertical scale of months indicated by the letters J, F, M, etc., in each year. The vertical lines under the letters O D and B represent the positions of the Outer Dowsing and Borkum lightvessels. Patches are shown above the base lines and traces as small vertical strokes below them. No traces were found on the records marked with an *. Additional records in the autumn of 1934 are shown in text-figure 3.*

PLATE II



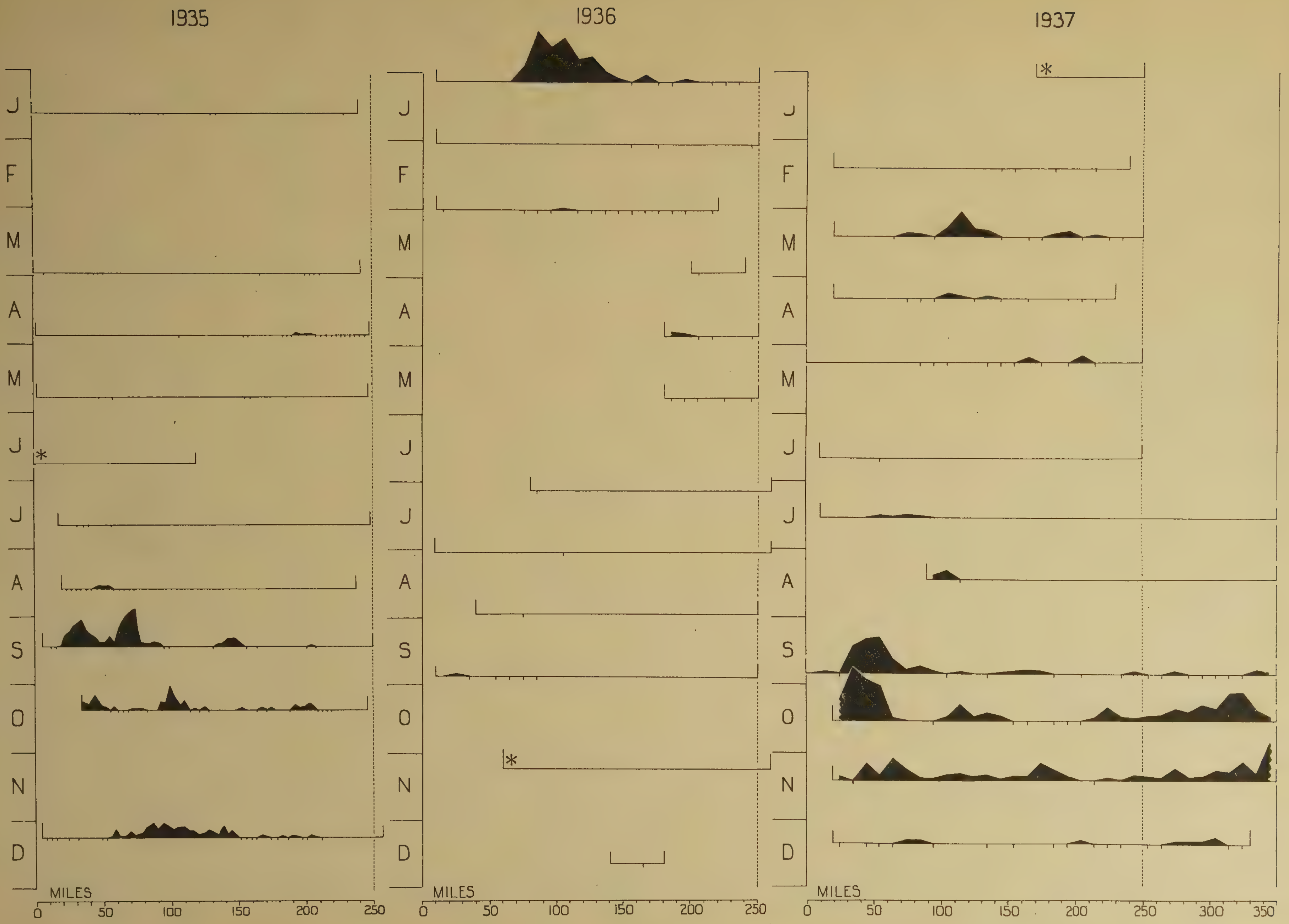
Records of **RHIZOSOLENIA STYLIFORMIS** *on the* Bremen *line,* 1935-1937, *arranged as explained on Plate I. The vertical line under the letter N represents the position of the* Norderney *lightvessel. The record marked 'Q' is of qualitative value only. Additional records in the autumn of each year are shown in text-figures 3 and 4.*

PLATE III



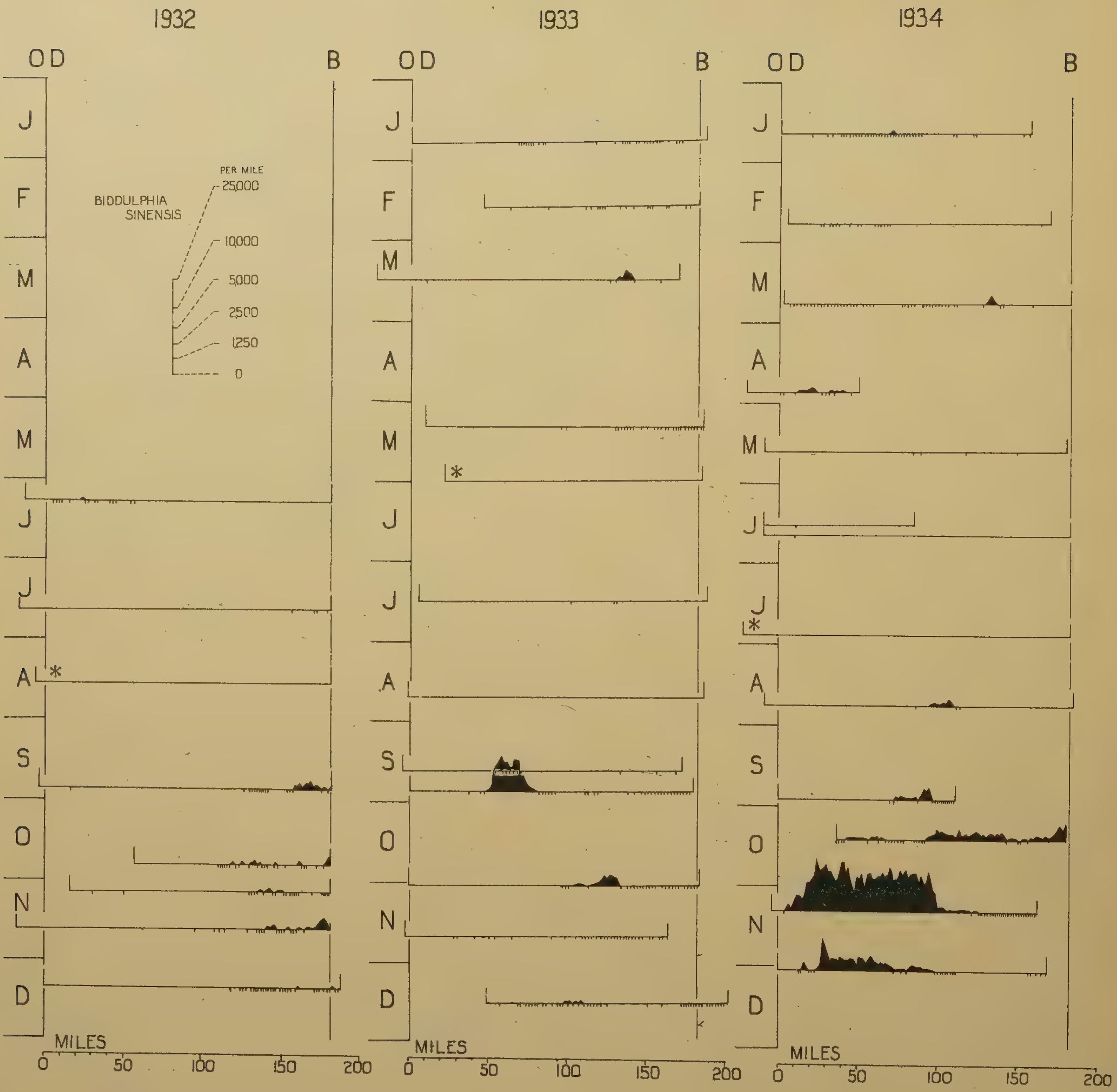
Records of **RHIZOSOLENIA STYLIFORMIS** on the Copenhagen *line*, 1932-1934, *arranged as explained on Plate I except that the vertical line on the left represents the position of the* Humber *lightvessel and the broken vertical line on the right marks the position of a point* 250 *miles from the lightvessel.*

PLATE IV



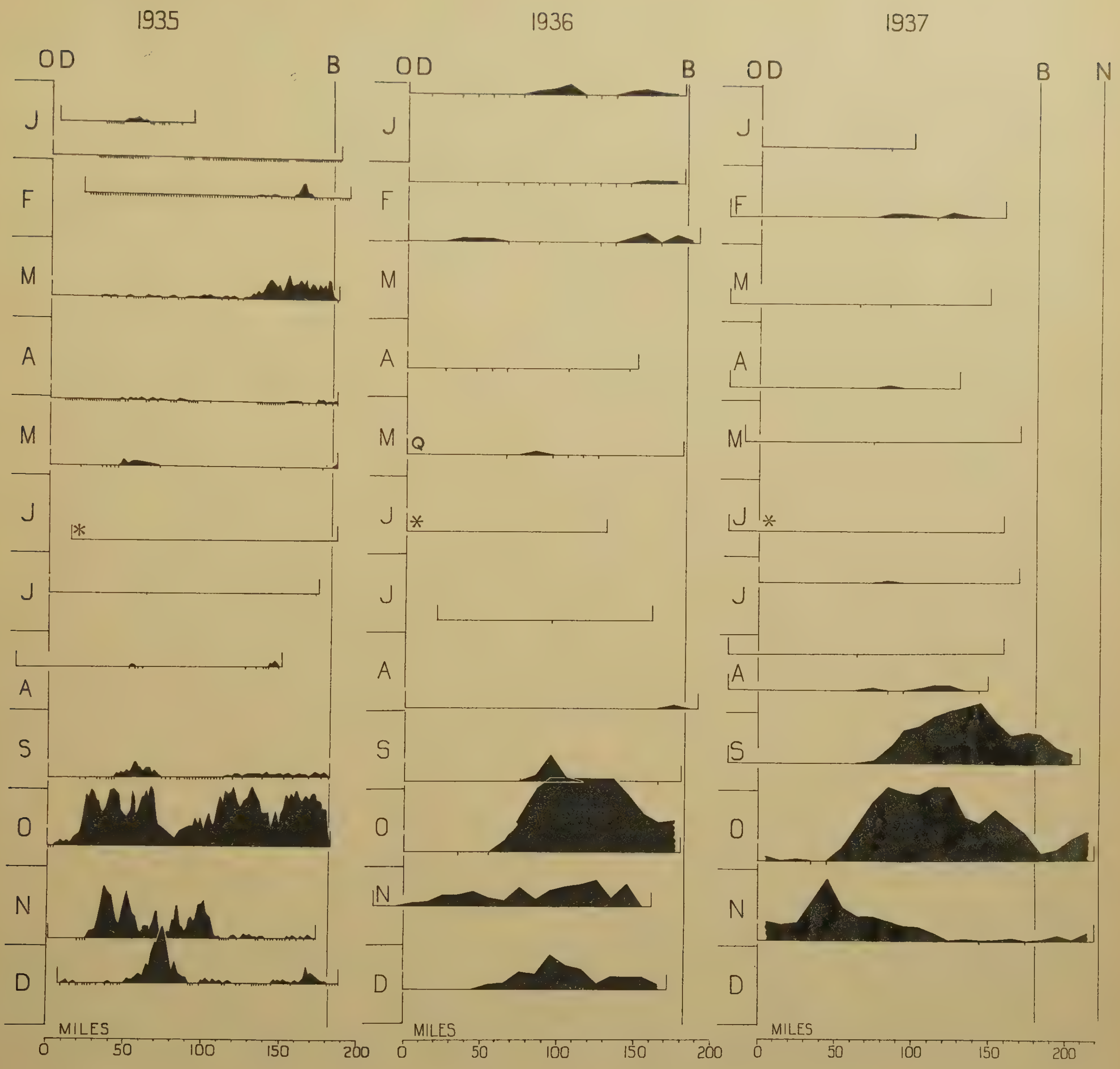
Records of **RHIZOSOLENIA STYLIFORMIS** on the Copenhagen line, 1935-1937, arranged as explained on Plate III.

PLATE V



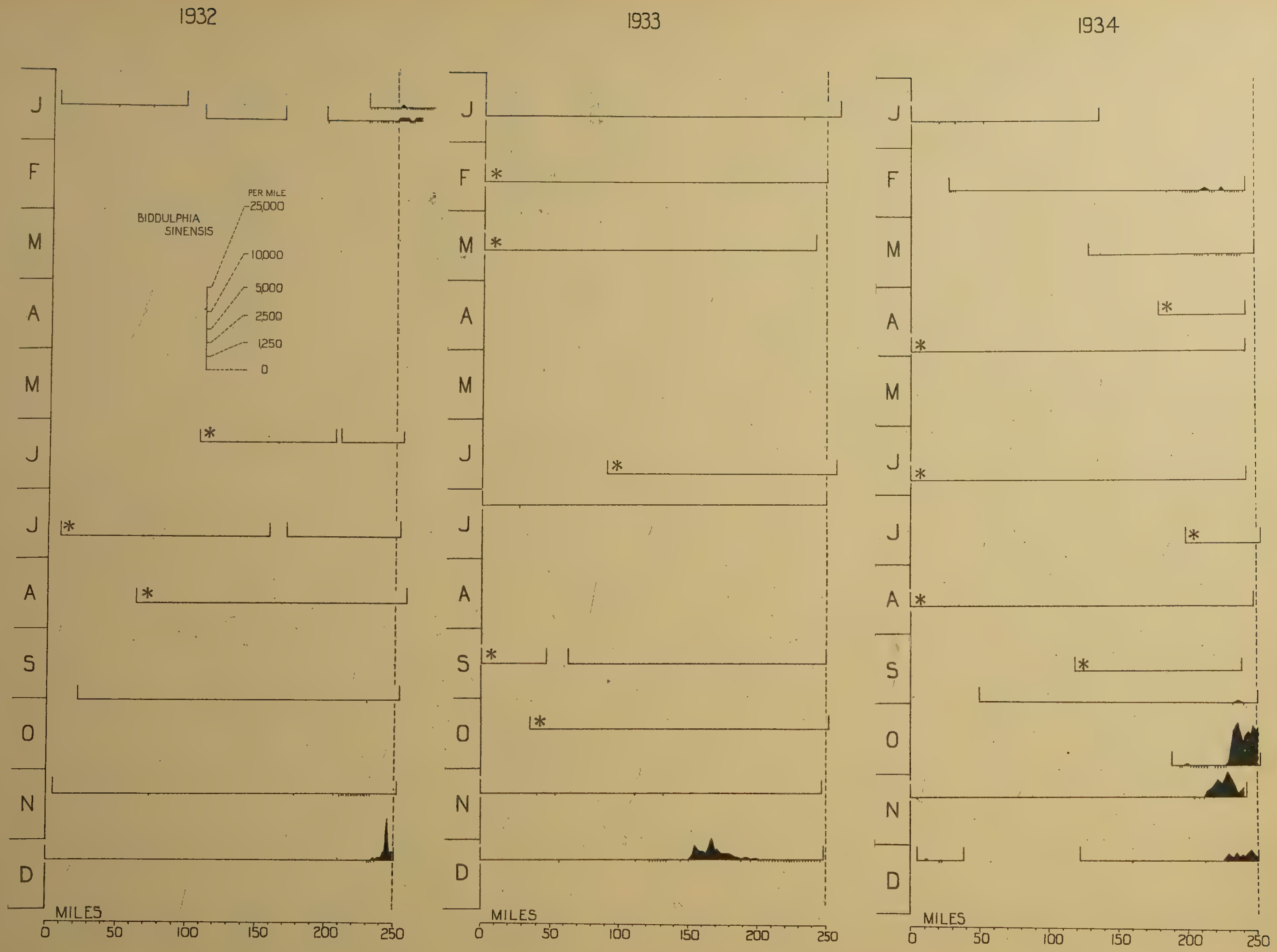
Records of **BIDDULPHIA SINENSIS** *on the* Bremen *line,* 1932-1934, *arranged as explained on Plate I. Additional records in the autumn of* 1934 *are shown in text-figure* 3.

PLATE VI



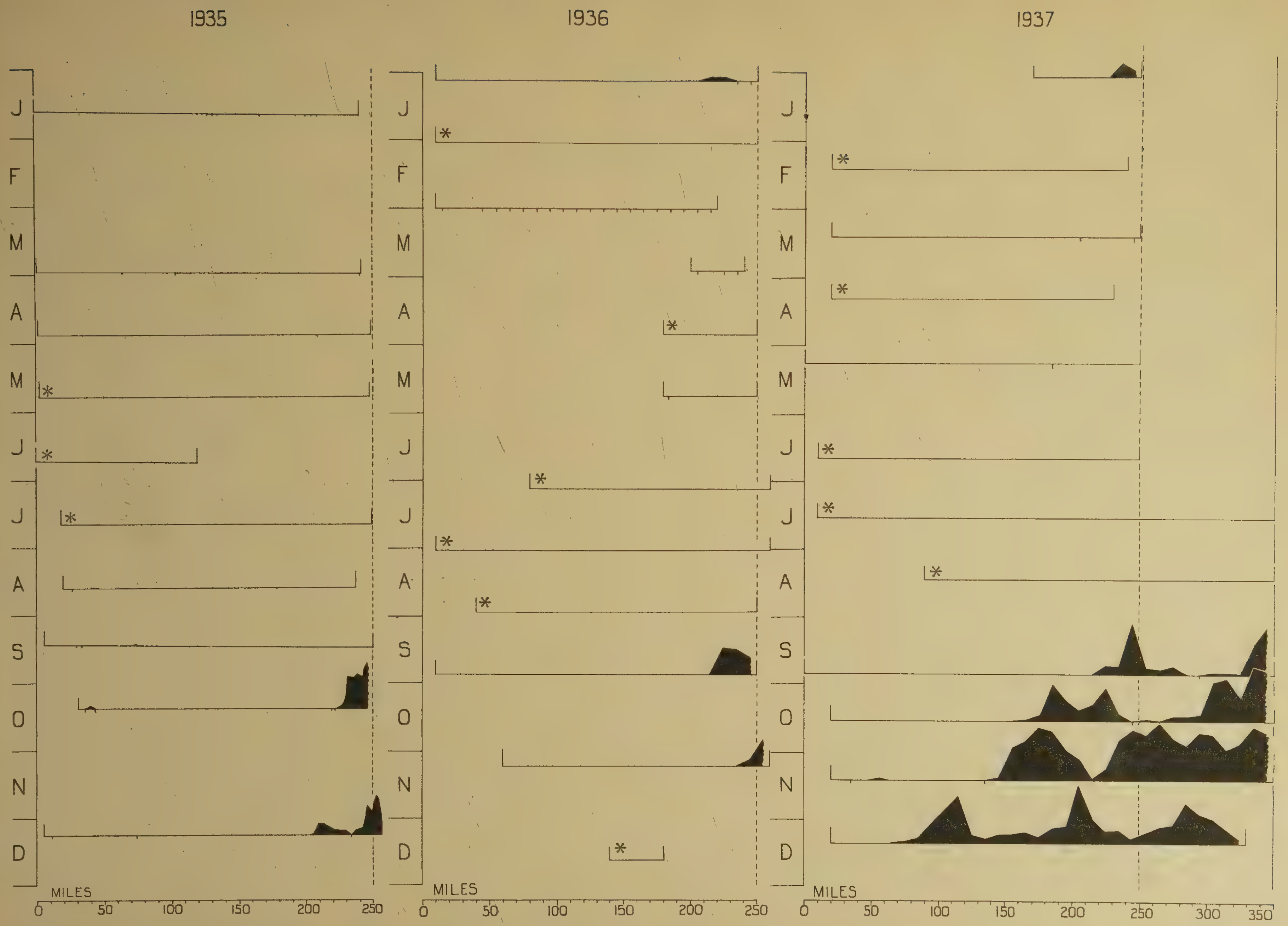
Records of **BIDDULPHIA SINENSIS** *on the* Bremen *line,* 1935-1937, *arranged as explained on Plates I and II. Additional records in the autumn of each year are shown in text-figures 3 and 4.*

PLATE VII



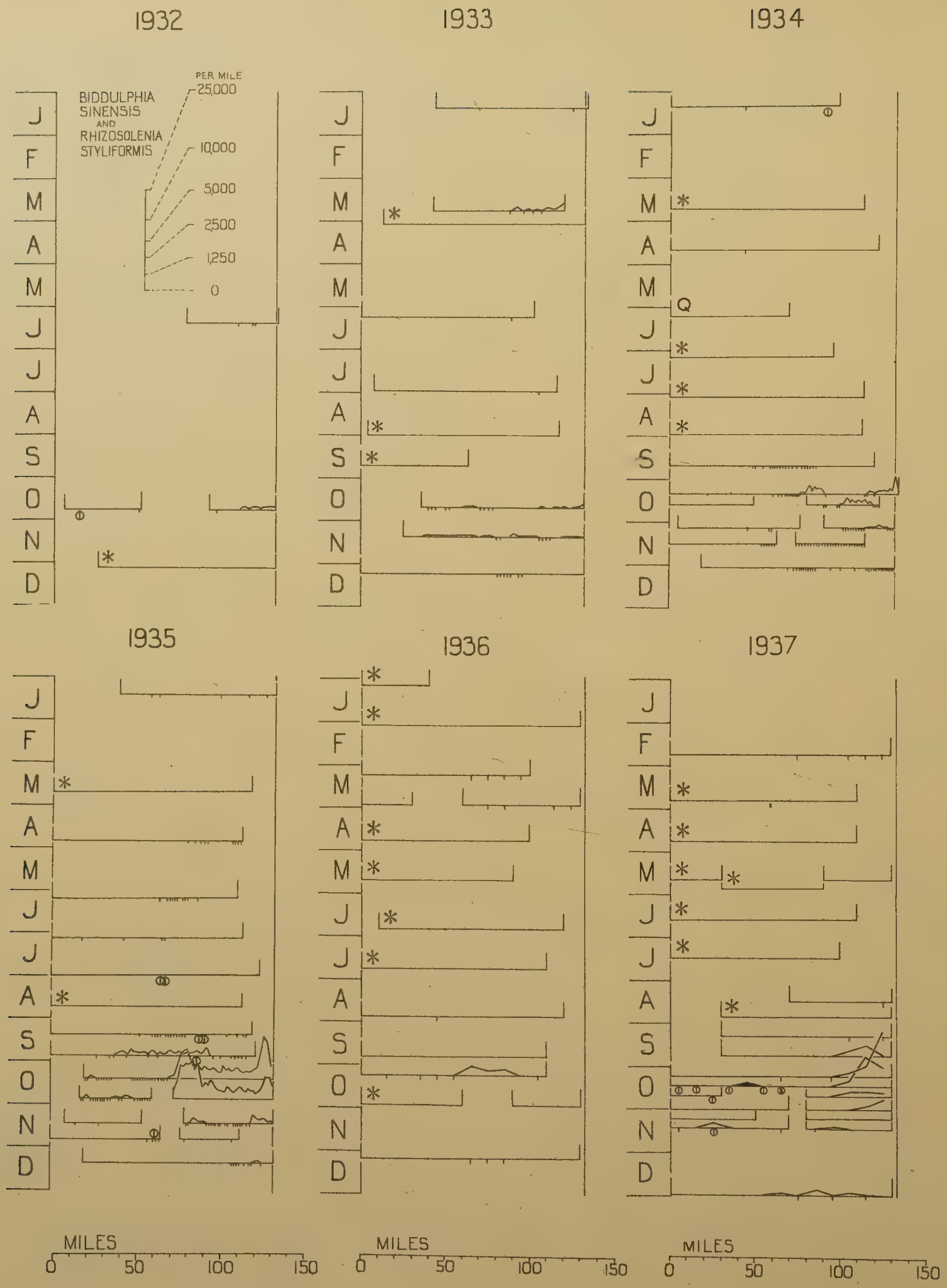
Records of **BIDDULPHIA SINENSIS** *on the* Copenhagen *line,* 1932-1934, *arranged as explained on Plate III.*

PLATE VIII



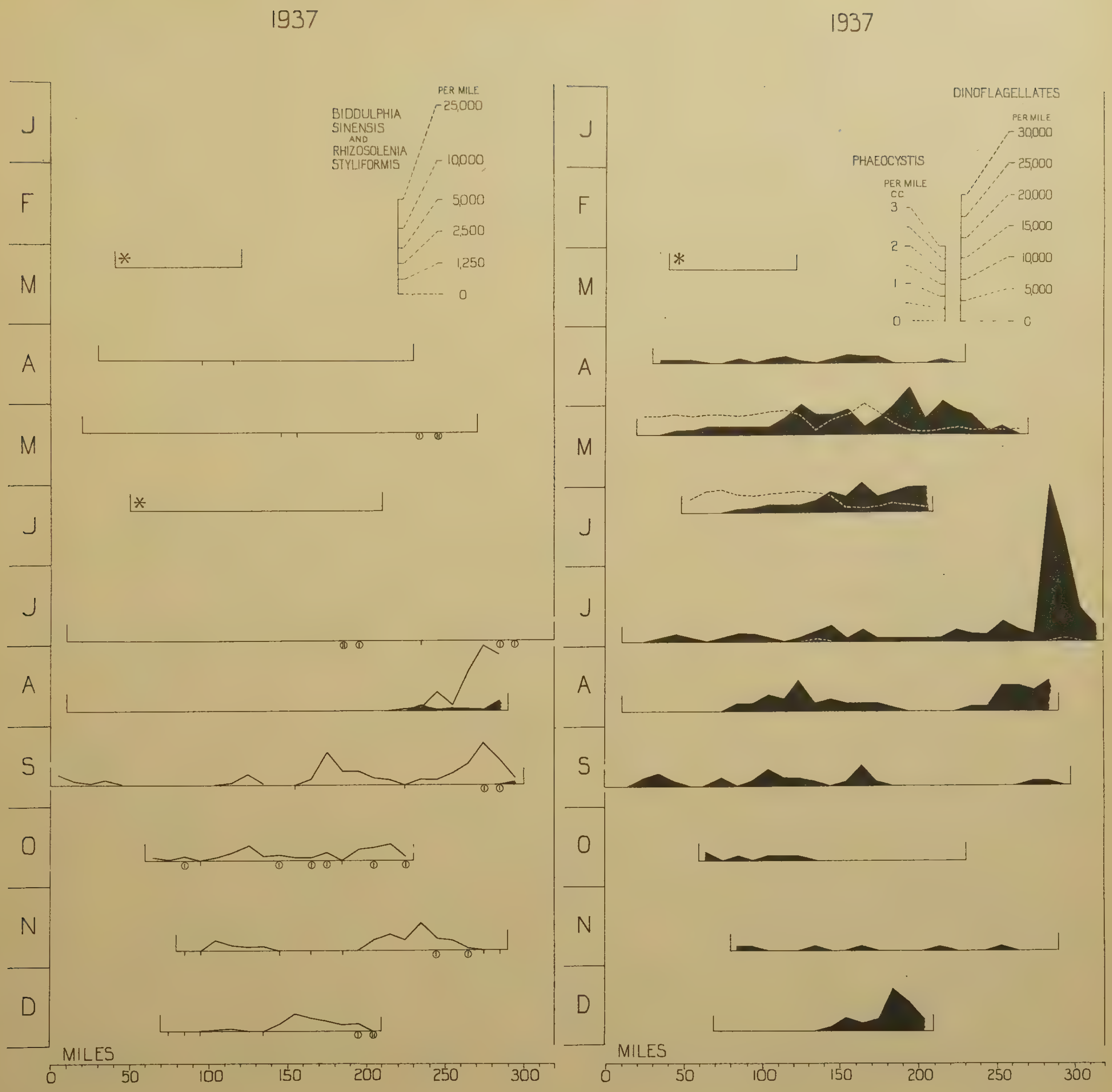
Records of ***BIDDULPHIA SINENSIS*** *on the* Copenhagen *line,* 1935-1937, *arranged as explained on Plate III.*

PLATE IX



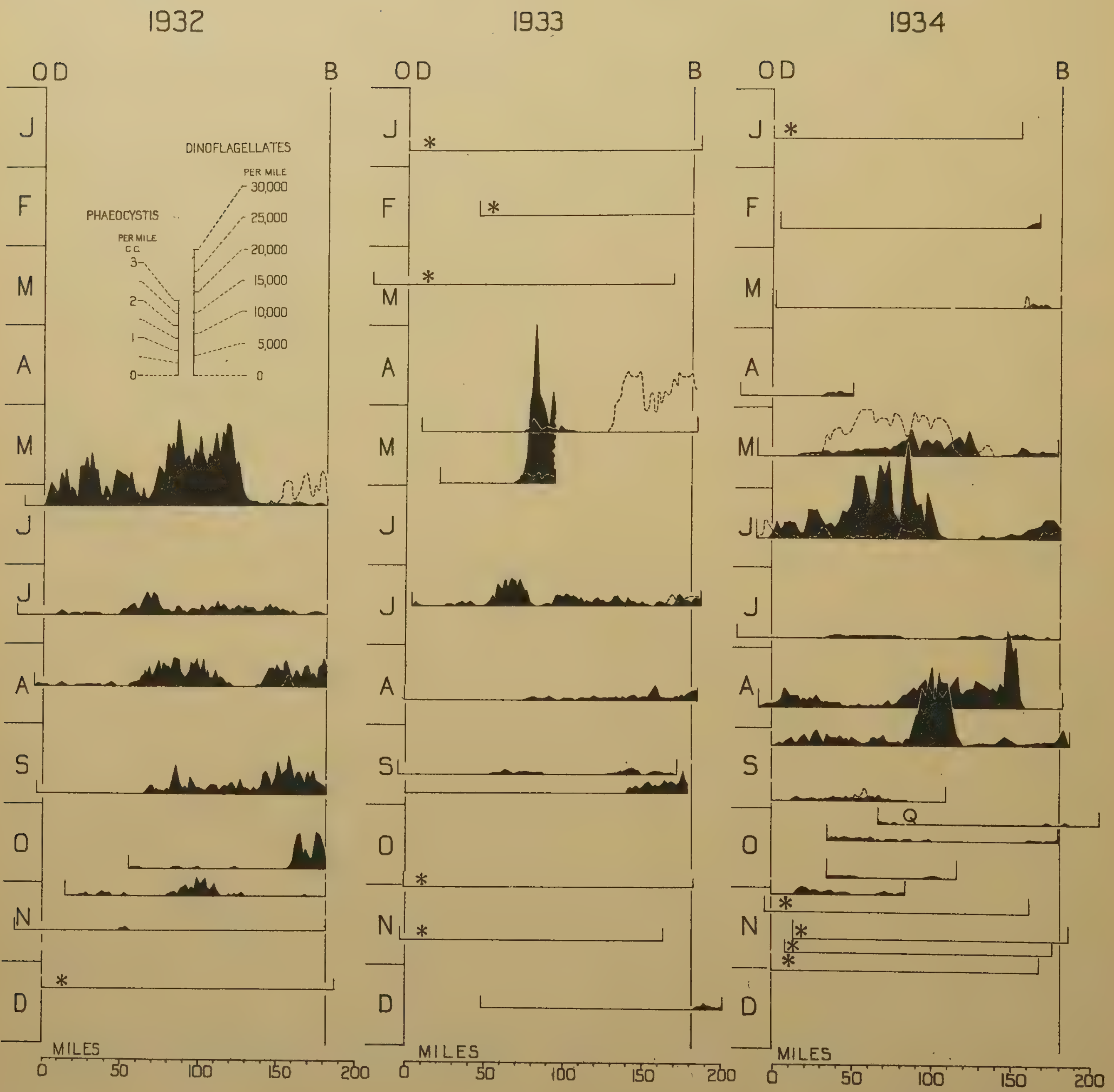
Records of **BIDDULPHIA SINENSIS** and **RHIZOSOLENIA STYLIFORMIS** on the Rotterdam line, 1932-1937. General arrangement as explained on Plate I except that the vertical lines to right and left represent the positions of the East Dudgeon and Maas lightvessels. Patches of B. SINENSIS shown as open line graphs and traces as vertical strokes below the base lines; R. STYLIFORMIS as blacked in graph (only one patch) and vertical strokes in circles below the base lines. When there are two strokes within one circle both forms are present as traces.

PLATE X



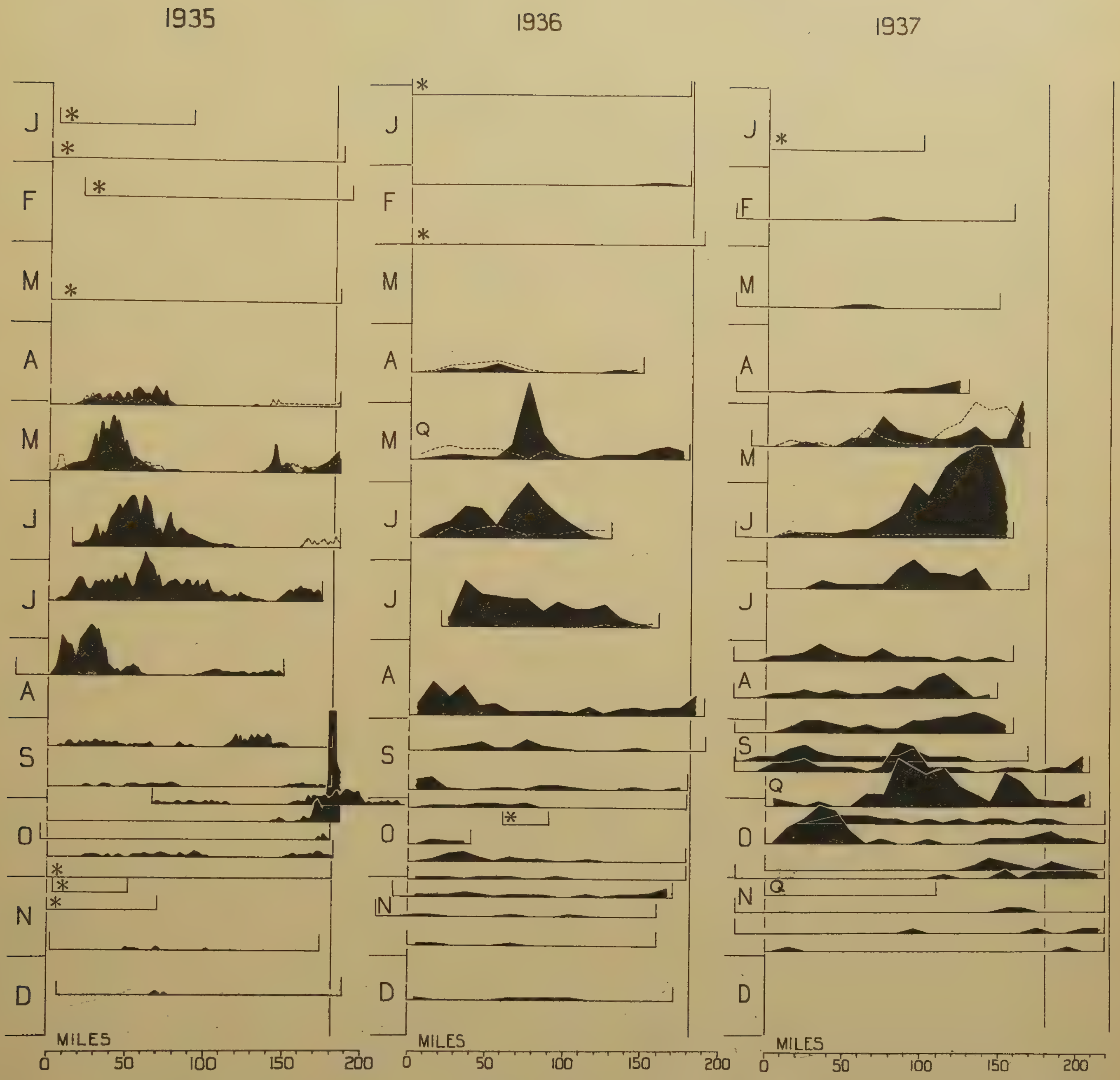
Records of ***BIDDULPHIA SINENSIS*** *and* ***RHIZOSOLENIA STYLIFORMIS*** *(left) and* ***DINOFLAGELLATES*** *and* ***PHAEOCYSTIS*** *(right) on the Esbjerg line in 1937. General arrangement as explained on Plate I except that the vertical lines to the right and left represent the positions of the Sunk and Graadyb lightvessels. B. SINENSIS shown as open line graphs, R. STYLIFORMIS and DINOFLAGELLATES as blacked-in graphs and PHAEOCYSTIS as broken line graphs. Traces of B. SINENSIS and R. STYLIFORMIS shown below the base lines as in Plate IX.*

PLATE XI



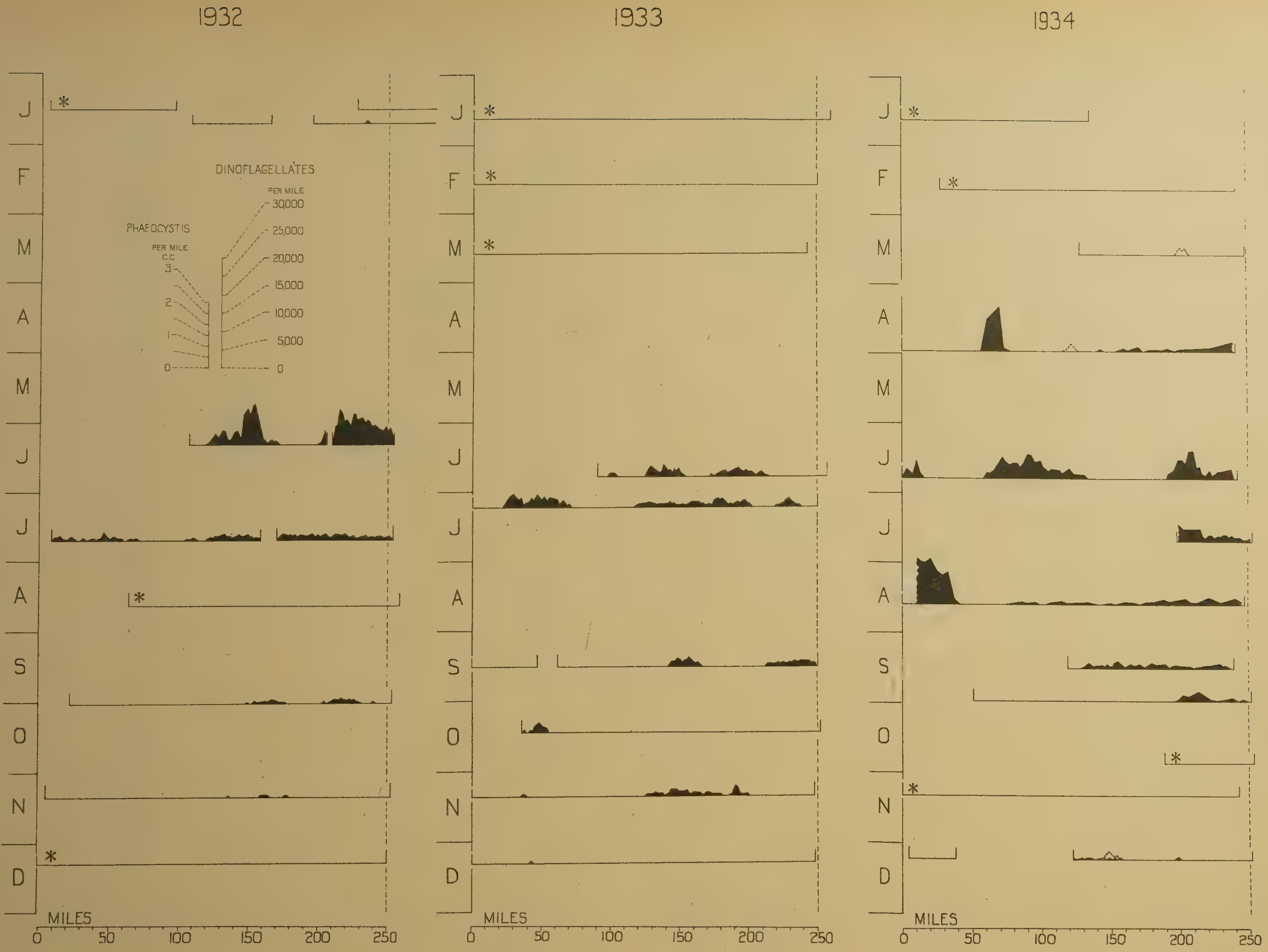
Records of **DINOFLAGELLATES** *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line) on the Bremen line, 1932-1934, arranged as explained on Plates I and II.*

PLATE XII



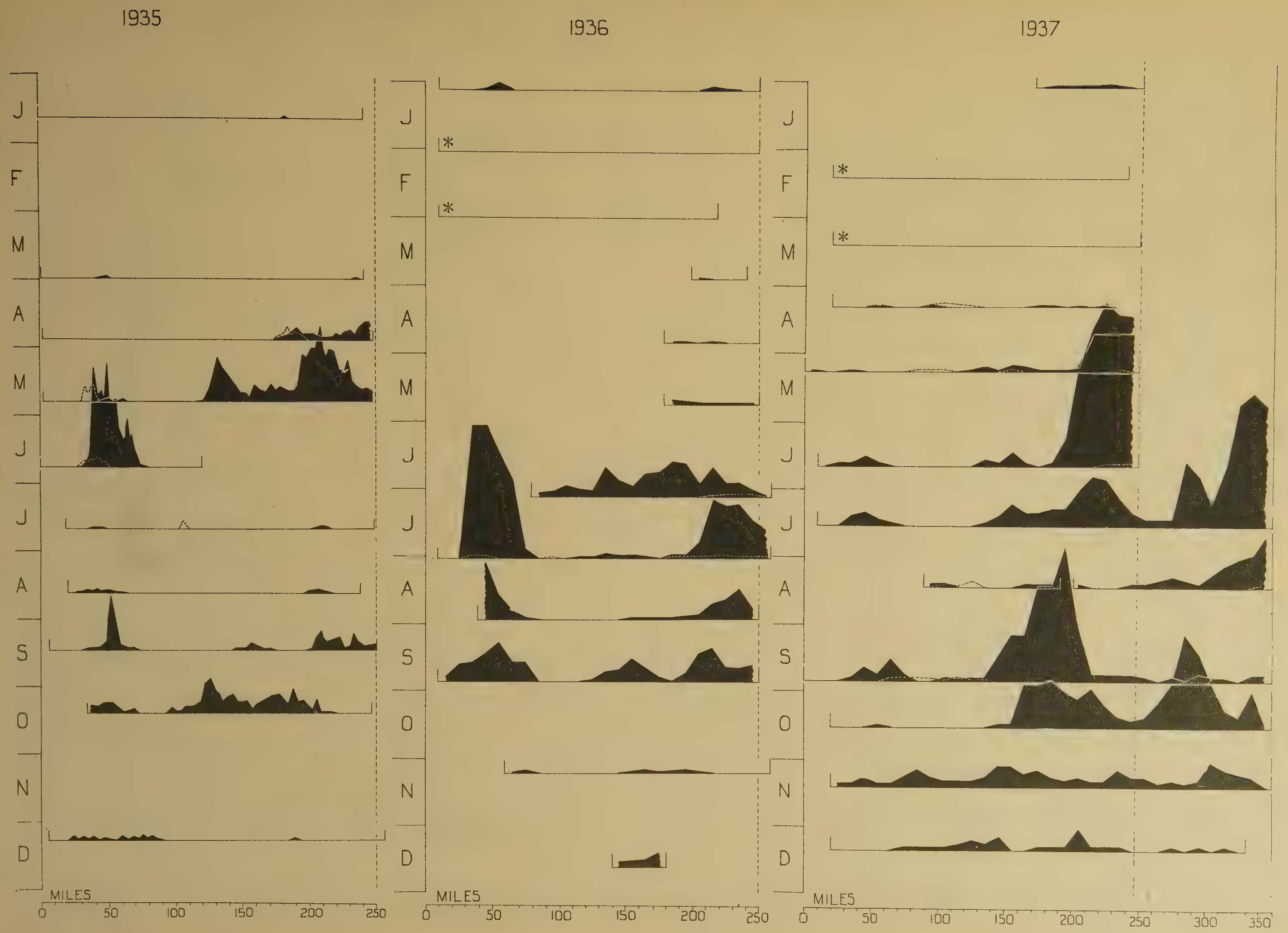
Records of **DINOFLAGELLATES** *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line) on the* Bremen *line,* 1935-1937 ; *arrangement and scale as on Plate XI.*

PLATE XIII



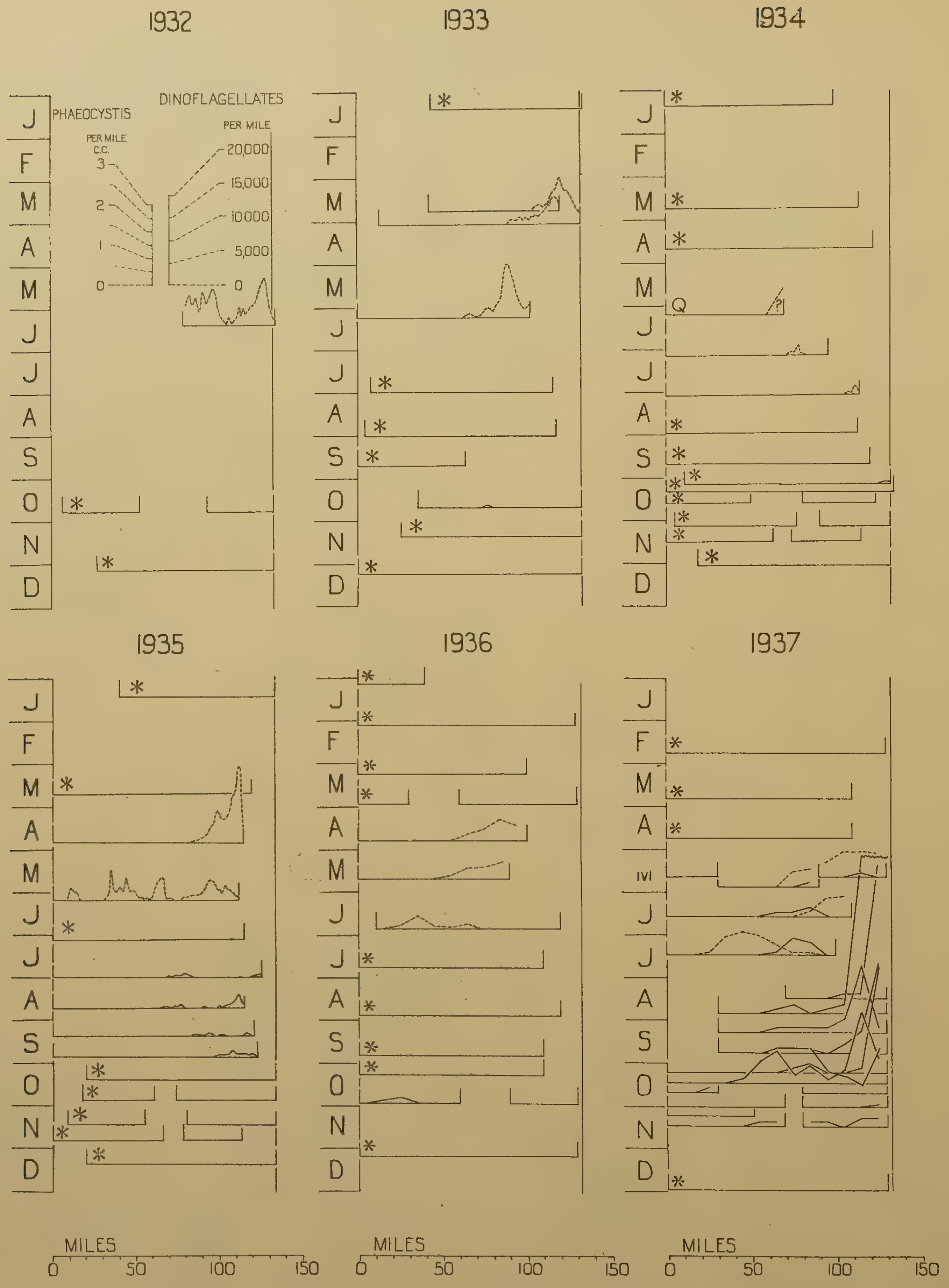
Records of **DINOFLAGELLATES** *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line) on the* Copenhagen *line,* 1932-1934, *arranged as explained on Plate III.*

PLATE XIV



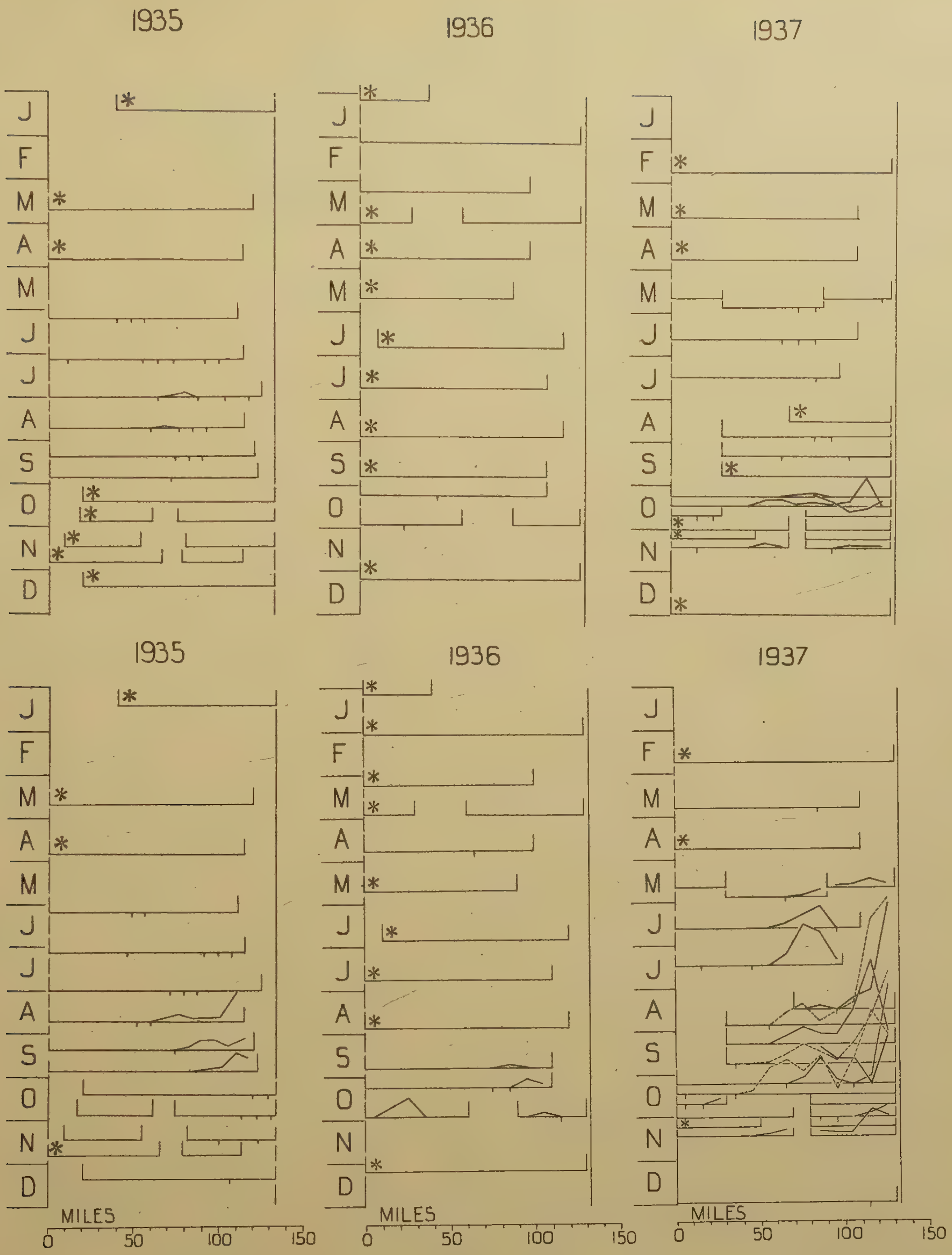
Records of **DINOFLAGELLATES** (blacked-in graph) and **PHAEOCYSTIS** (broken line) on the Copenhagen line, 1935-1937; arrangements and scale as on Plate XIII.

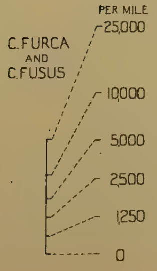
PLATE XV



Records of **DINOFLAGELLATES** (continuous line) and **PHAEOCYSTIS** (broken line) on the Rotterdam line, 1932-1937, arranged as explained on Plate IX. 'Q' indicates a record of qualitative value only.

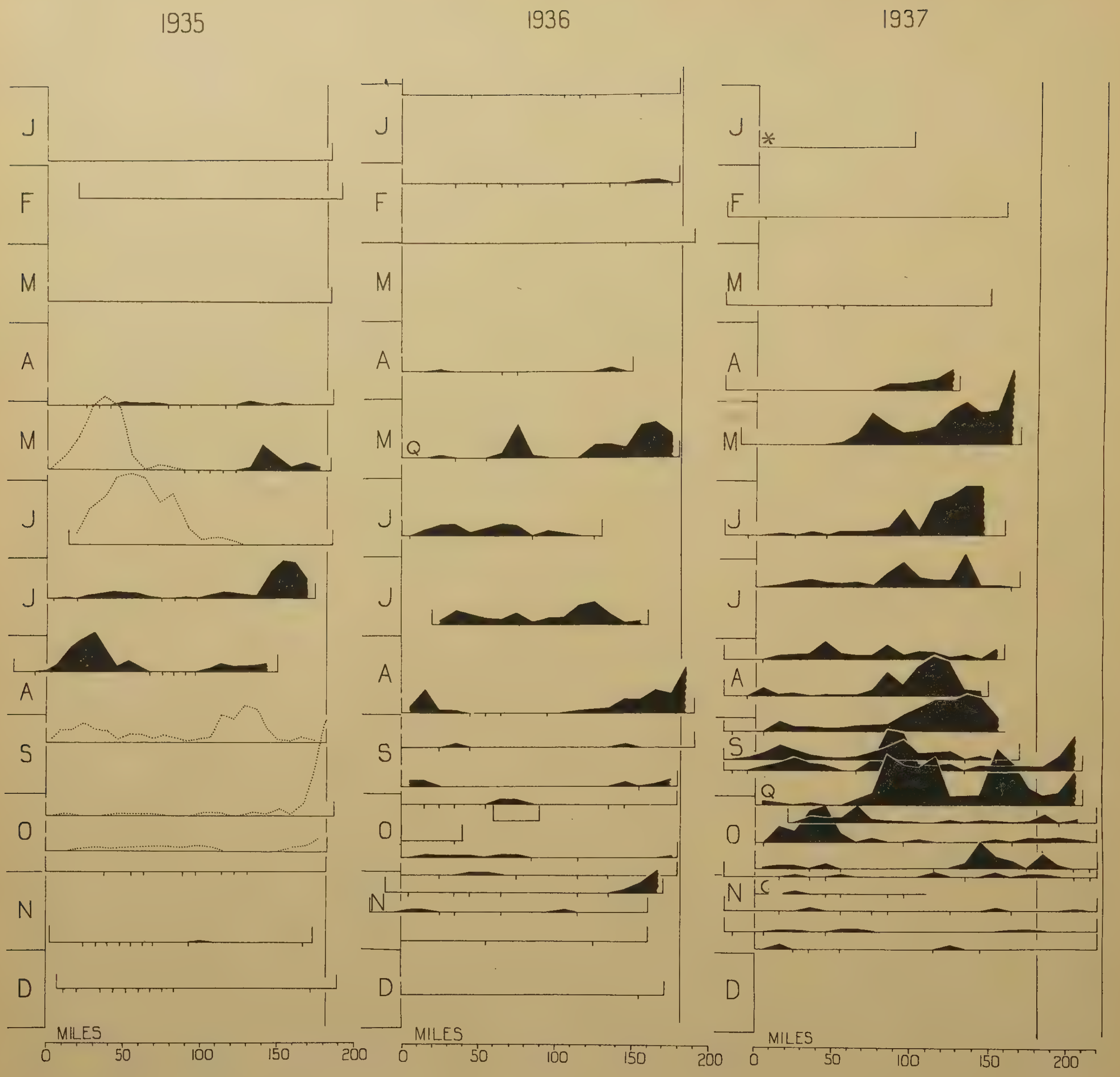
PLATE XVI

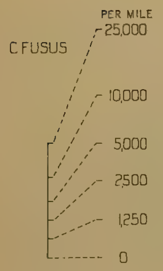




Records of **CERATIUM FURCA** *(above) and* **C. FUSUS** *(below) on the Rotterdam line, 1935-1937, arranged as explained on Plate IX. The scale is the same as that on Plate XVII. For the sake of clarity alternate continuous and broken lines have been used for C. FUSUS in the autumn of 1937.*

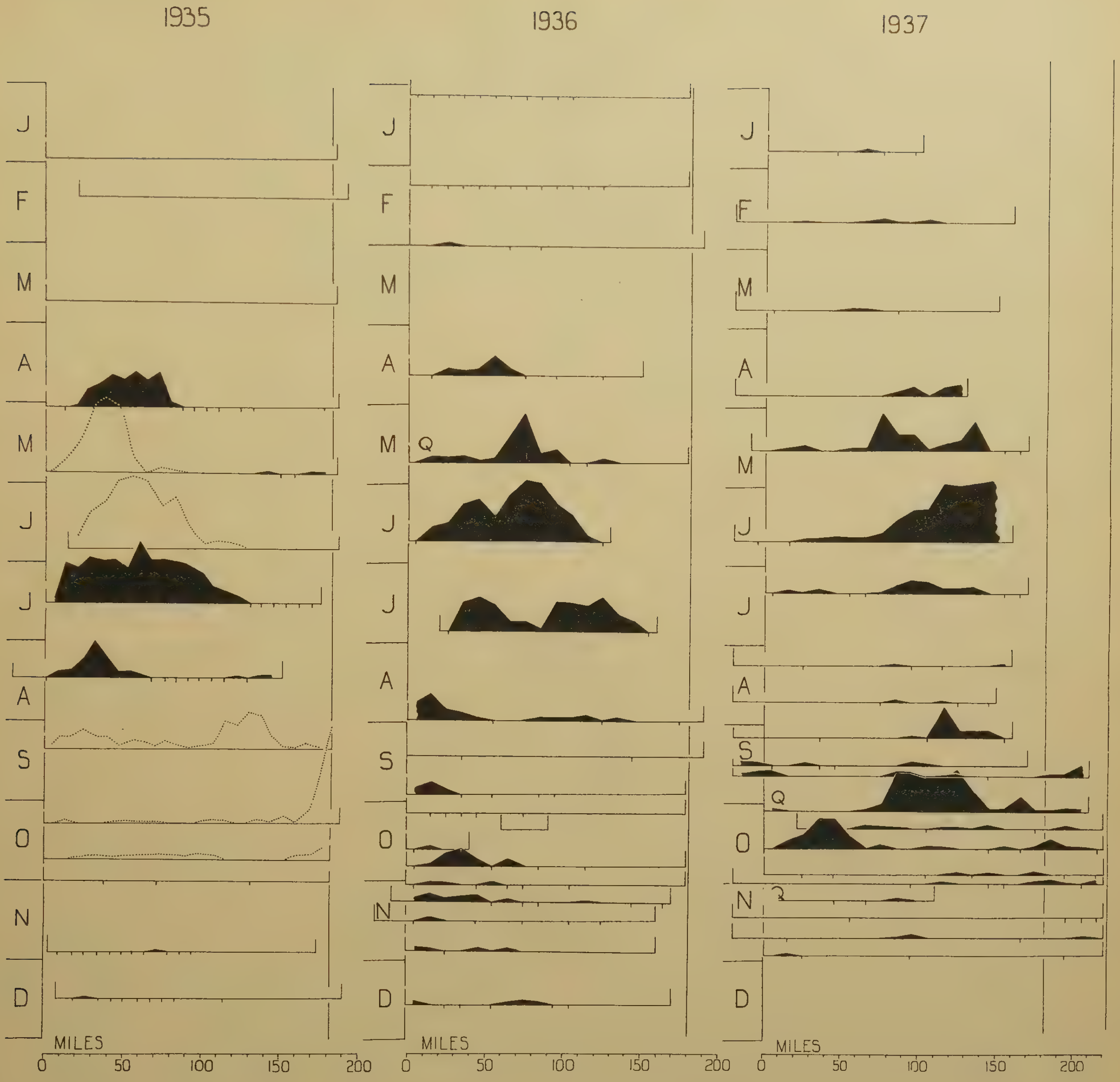
PLATE XVII

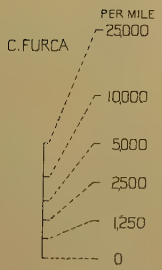




Records of **CERATIUM** **FUSUS** ~~**FURCA**~~ (blacked-in) on the Bremen line, 1935-1937, arranged as explained on Plates I and II. On a few occasions in 1935, when no detailed analysis was made, the corresponding graphs of Total Dinoflagellates have been provided in dotted line.

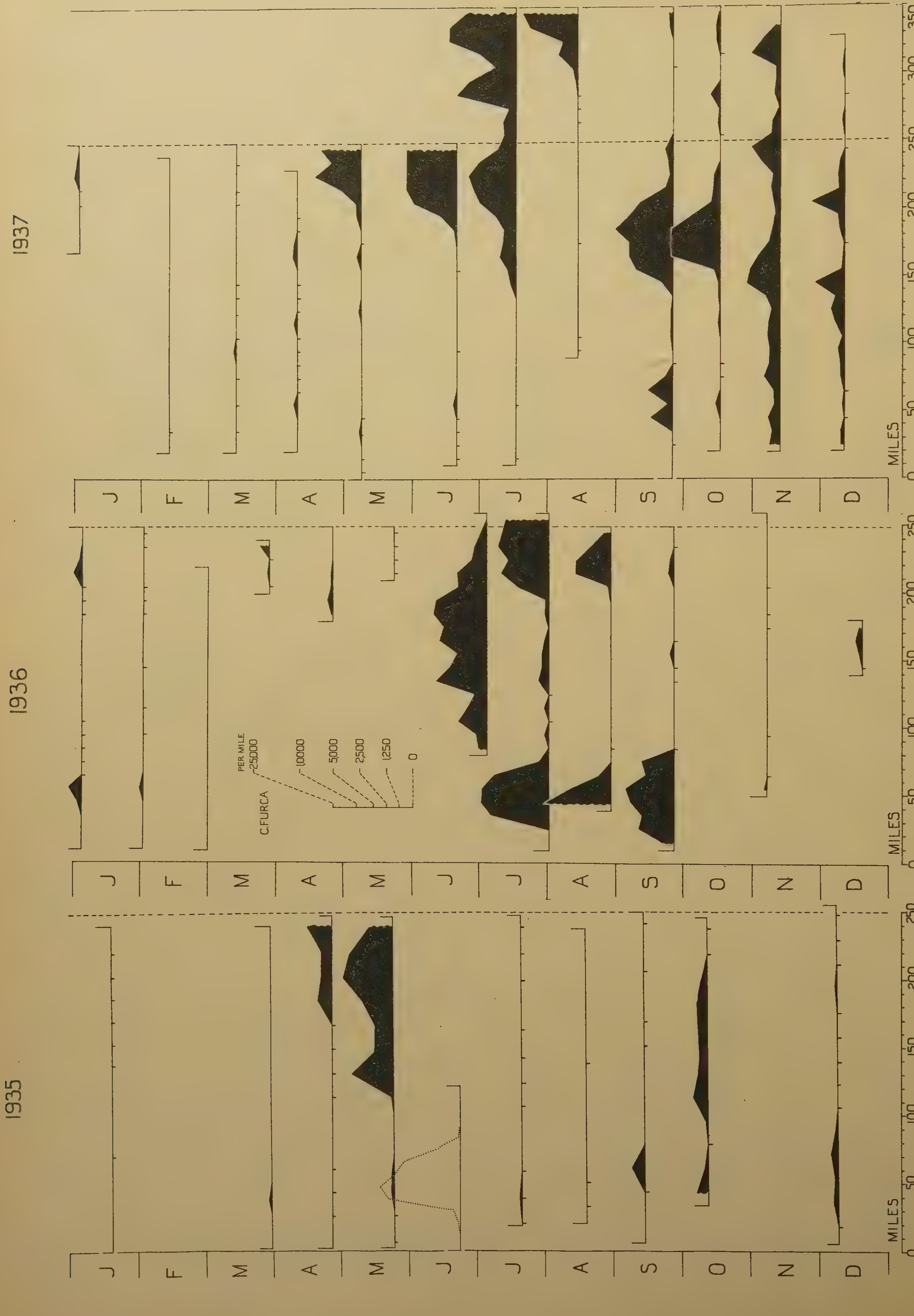
PLATE XVIII





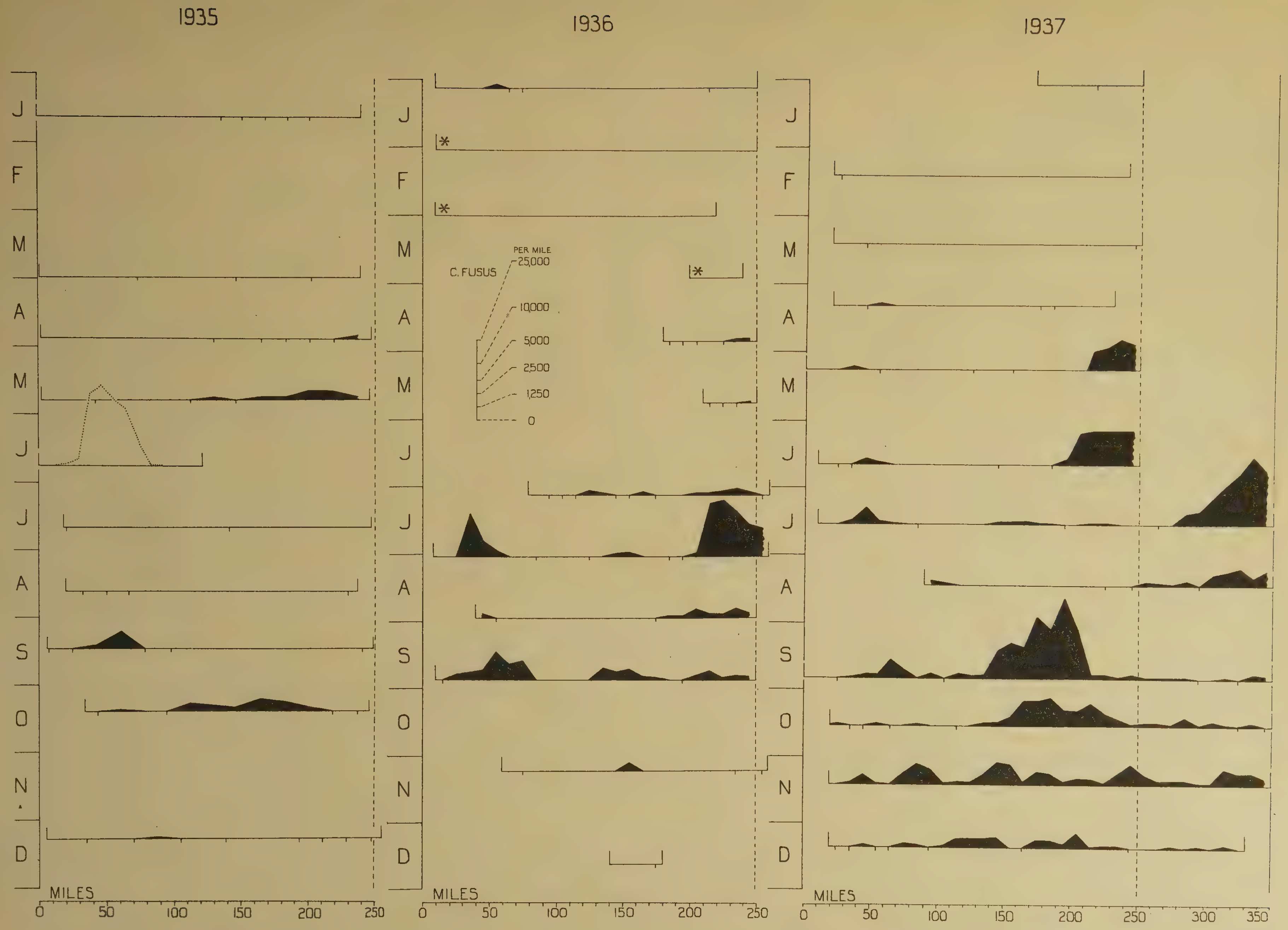
Records of *CERATIUM* ~~FUSUS~~ FURCA (blacked-in) on the Bremen line, 1935-1937, arranged as explained on Plate XVII.

PLATE XIX



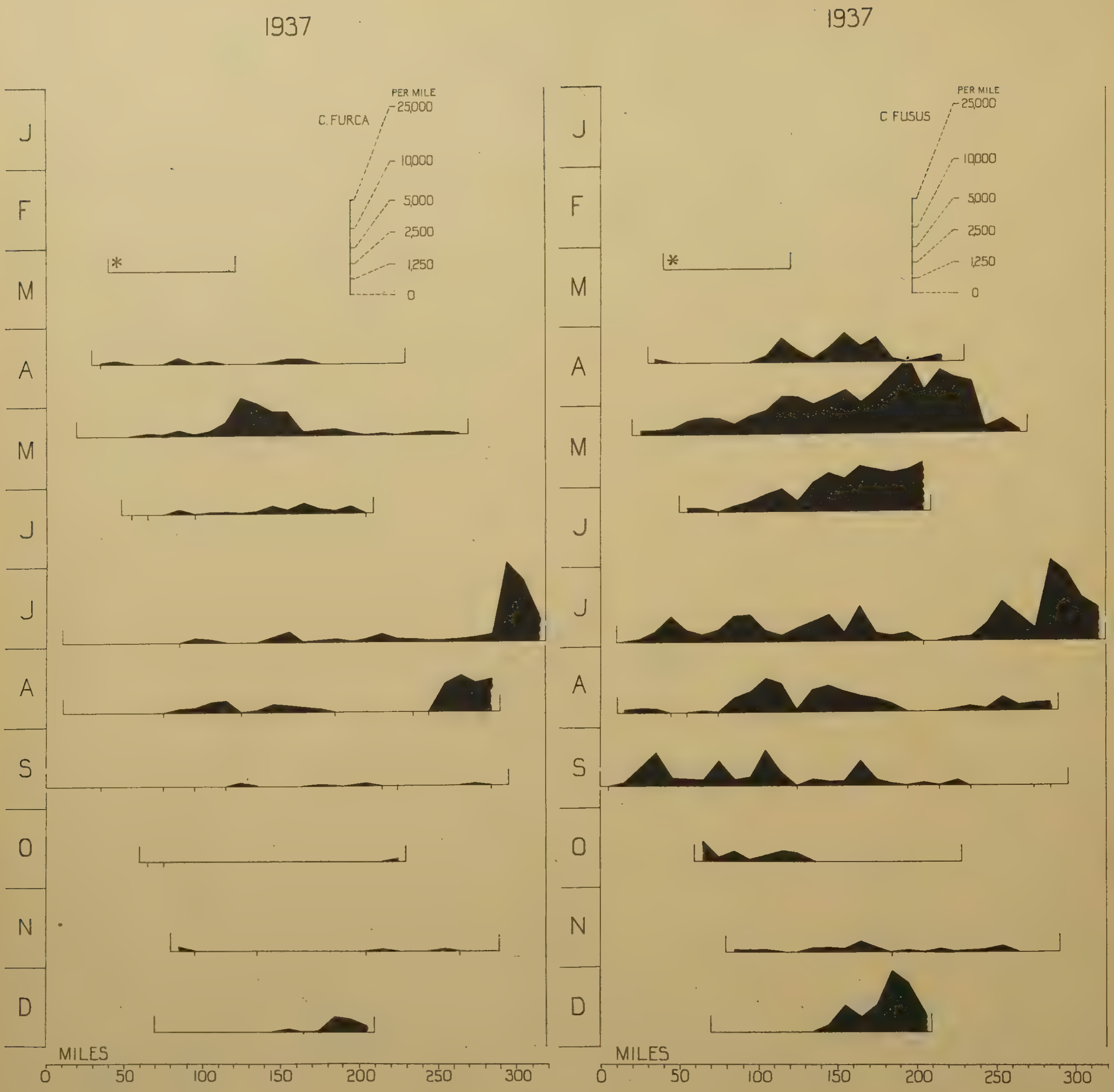
Records of **CERATIUM FURCA** (blacked-in) on the Copenhagen line, 1935-1937, arranged as explained on Plate XVII, except that the vertical lines on the left represent the position of the Humber lightvessel.

PLATE XX



Records of **CERATIUM FUSUS** (blacked-in) on the Copenhagen line, 1935-1937, arranged as explained on Plate XVII, except that the vertical lines on the left represent the position of the Humber lightvessel.

PLATE XXI



Records of **CERATIUM FURCA** *(left) and* **C. FUSUS** *(right) on the Esbjerg line, 1937, arranged as explained on Plate XVII, except that the vertical lines on the left represent the position of the Sunk lightvessel.*

PLATES XXII–LXIV

MAPS SHOWING THE MONTHLY DISTRIBUTION OF THE PHYTOPLANKTON IN THE SOUTHERN NORTH SEA JUNE 1932 TO DECEMBER 1937

The following Explanation relates to PLATES XXII–XXXVI

This series of maps has been prepared to show the distribution of ***RHIZOSOLENIA STYLIFORMIS*** and ***BIDDULPHIA SINENSIS*** in the southern North Sea month by month from June 1932 to December 1937. Usually only one representative record is shown in each month for each line, but more have been obtained in the autumns of the later years ; some of these have been included in the standard series, but others for 1935-1937 are shown in additional maps at the end of the series on Plates XXXV and XXXVI. A few remaining graphs not shown will be found in text-figures 3 and 4.

RHIZOSOLENIA STYLIFORMIS is shown as a blacked-in graph or vertical strokes below the base lines (traces).

BIDDULPHIA SINENSIS is shown as a broken line graph or horizontal strokes below the base lines (traces).

The date of each record is shown at the eastern end of each line.

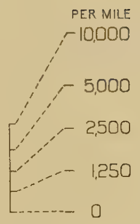
The letters H, OD, D, N, M and B indicate the HUMBER, OUTER DOWSING, DUDGEON, NEWARP, MAAS and BORKUM lightvessels respectively.

The position of the 20 fathom contour of the DOGGER BANK has been indicated by a faint dotted line.

The first records, for June 1932, are shown in the map on the right.

PLATE XXII

Scale for
Plates XXII—XXXVI :



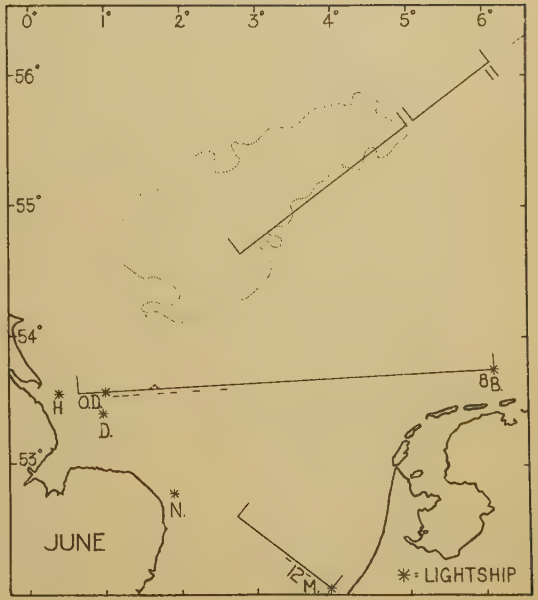
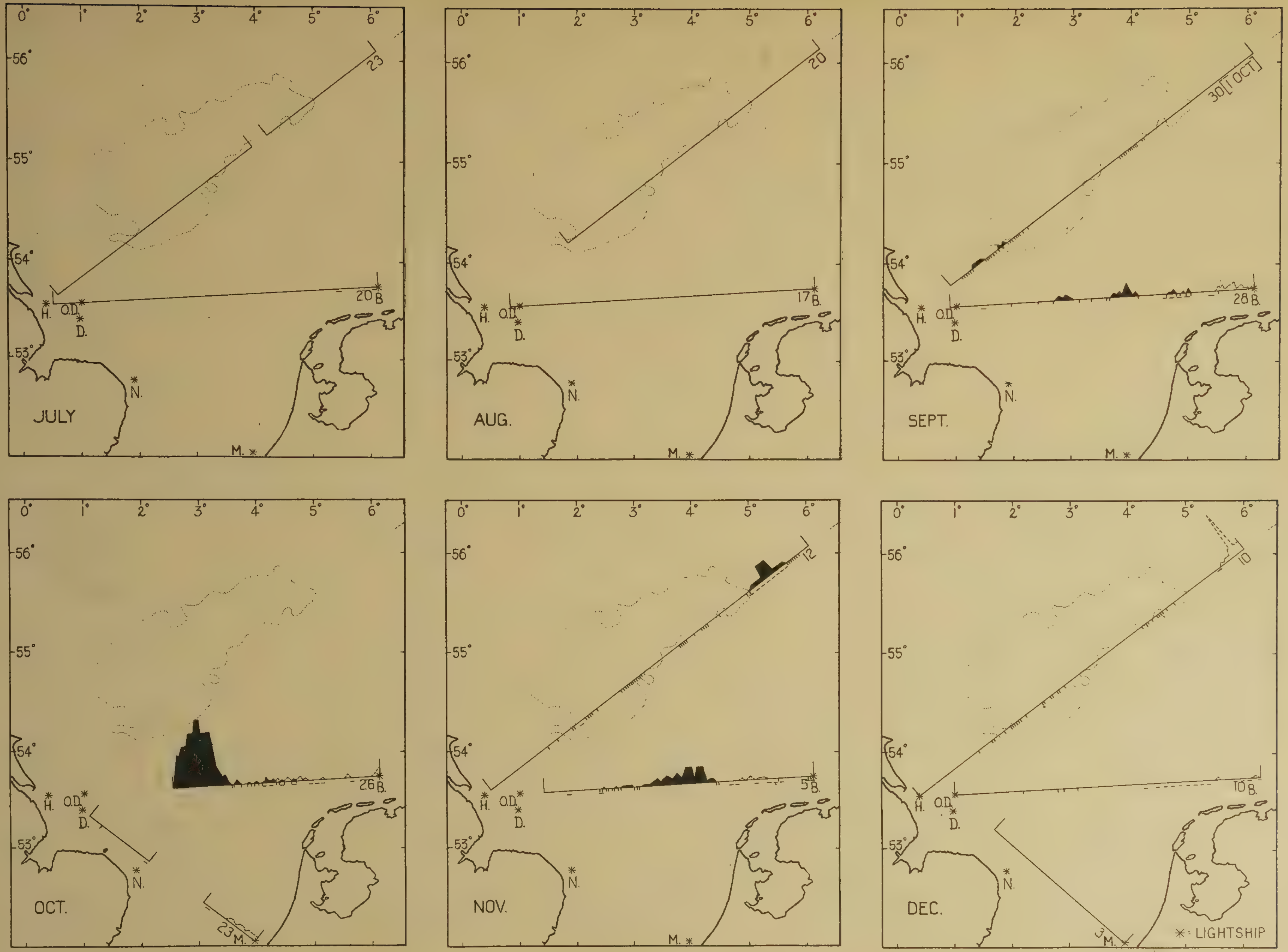
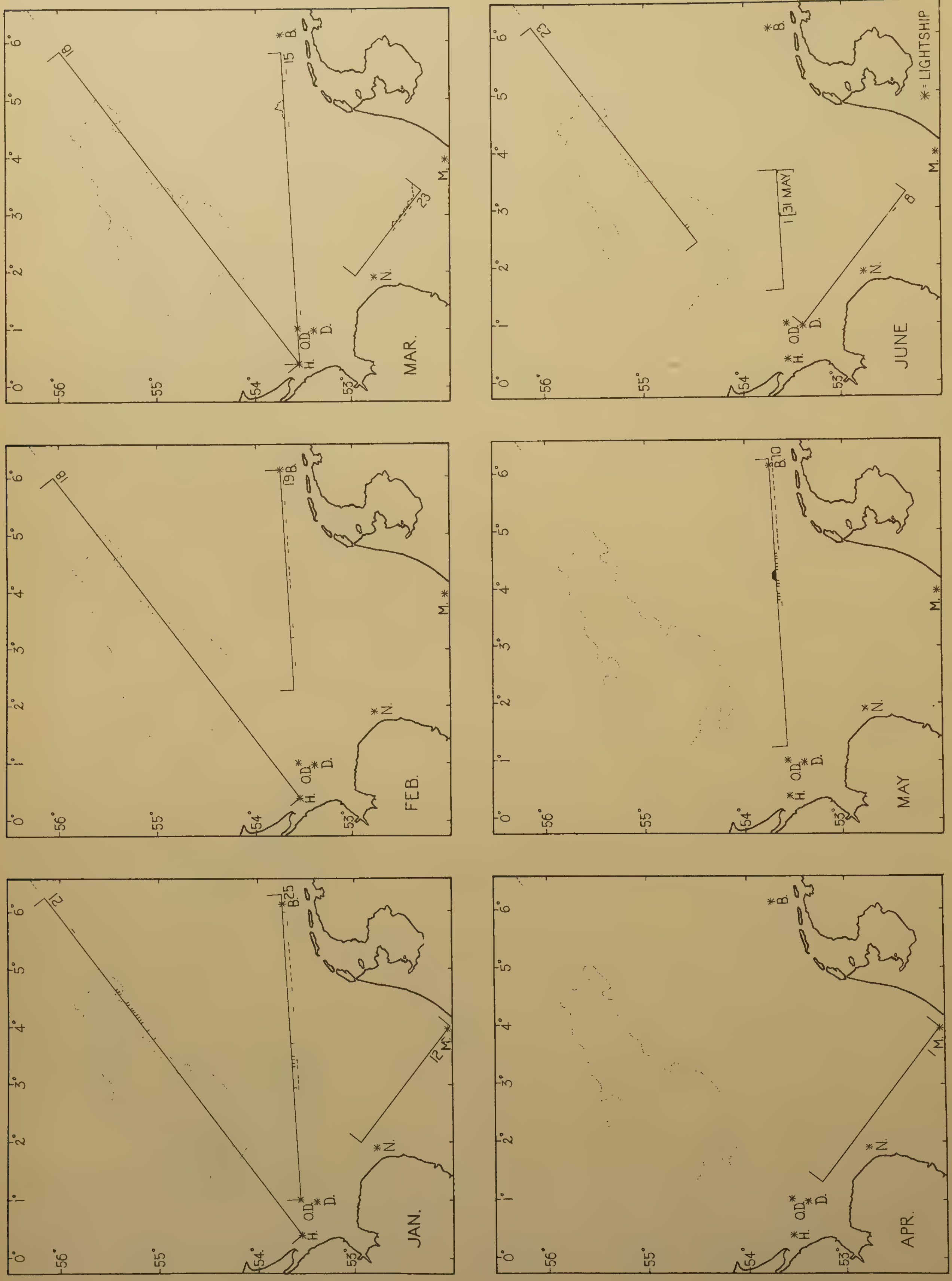


PLATE XXIII


JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
23
20 B.
20
17 B.
30 [1 OCT]
28 B.
26 B.
23 M.
12
5 B.
10
10 B.
3 M.
✱ : LIGHTSHIP

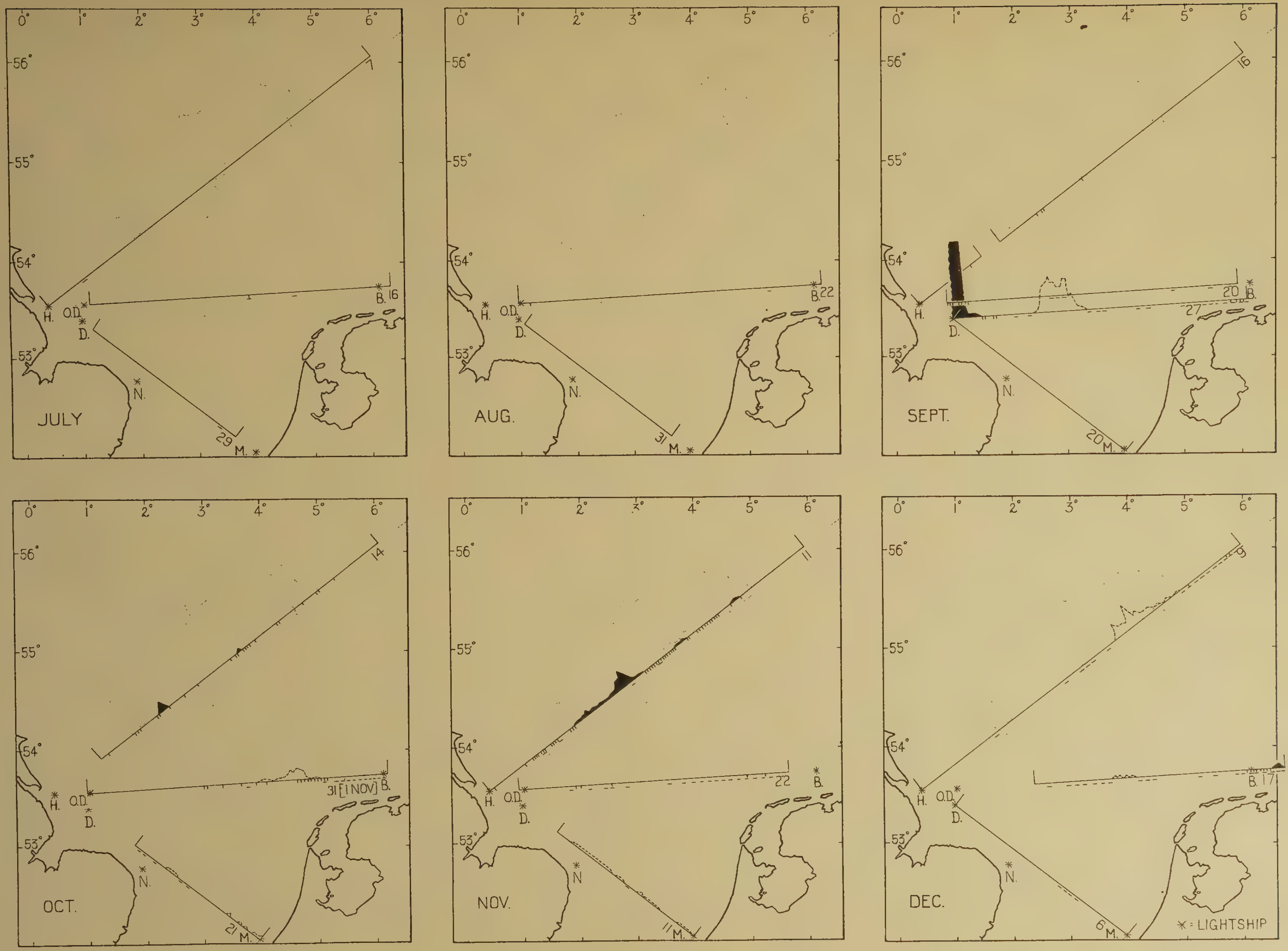
RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* ***BIDDULPHIA SINENSIS*** *(broken line), 1932, for further explanation see Plate XXII.*

PLATE XXIV

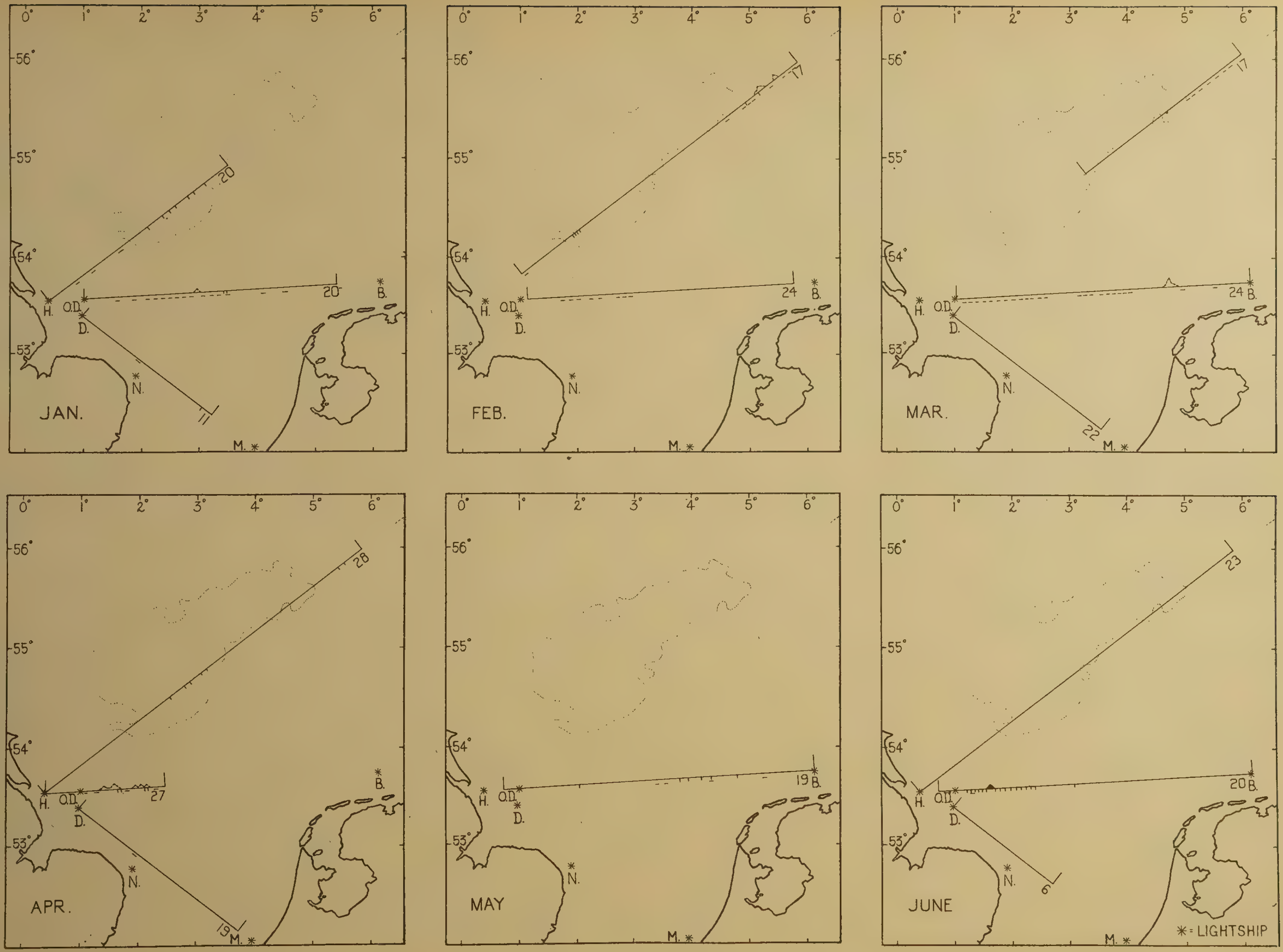

JAN.
FEB.
MAR.
APR.
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
H.
O.D.
D.
N.
M.
B.
12
12 M.
25
18
19 B.
15
23
1 M.
10
1 [31 MAY]
8
✱ = LIGHTSHIP

RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* ***BIDDULPHIA SINENSIS*** *(broken line), 1933, for further explanation see Plate XXII.*

PLATE XXV

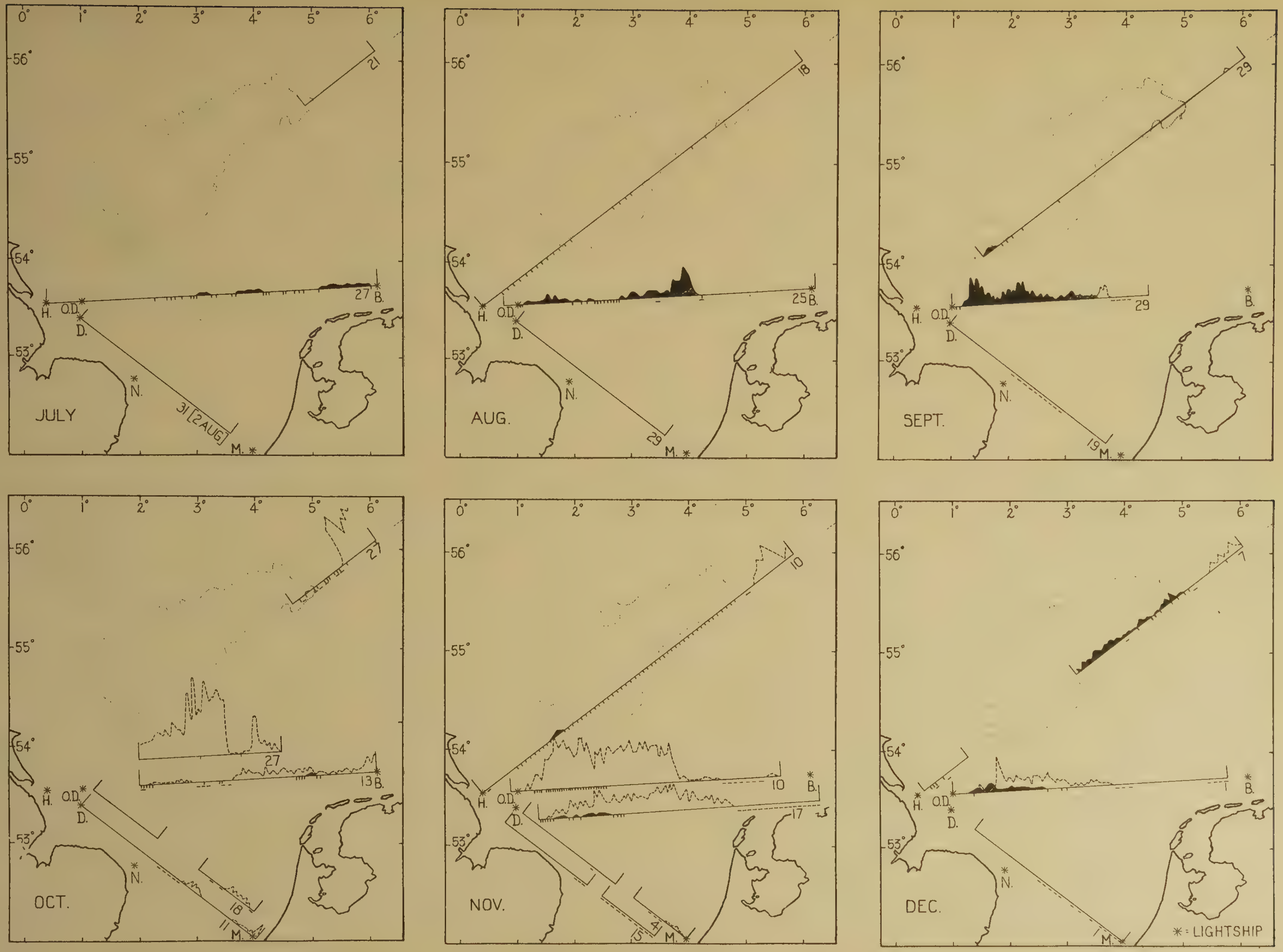

JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
H.
O.D.
D.
N.
M.
B.
29
16
31
22
20
27
16
21
31 [1 NOV]
14
11
6
17
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
* = LIGHTSHIP

RHIZOSOLENIA STYLIFORMIS *(blacked-in group) and* **BIDDULPHIA SINENSIS** *(broken line), 1933, for further explanation see Plate XXII.*

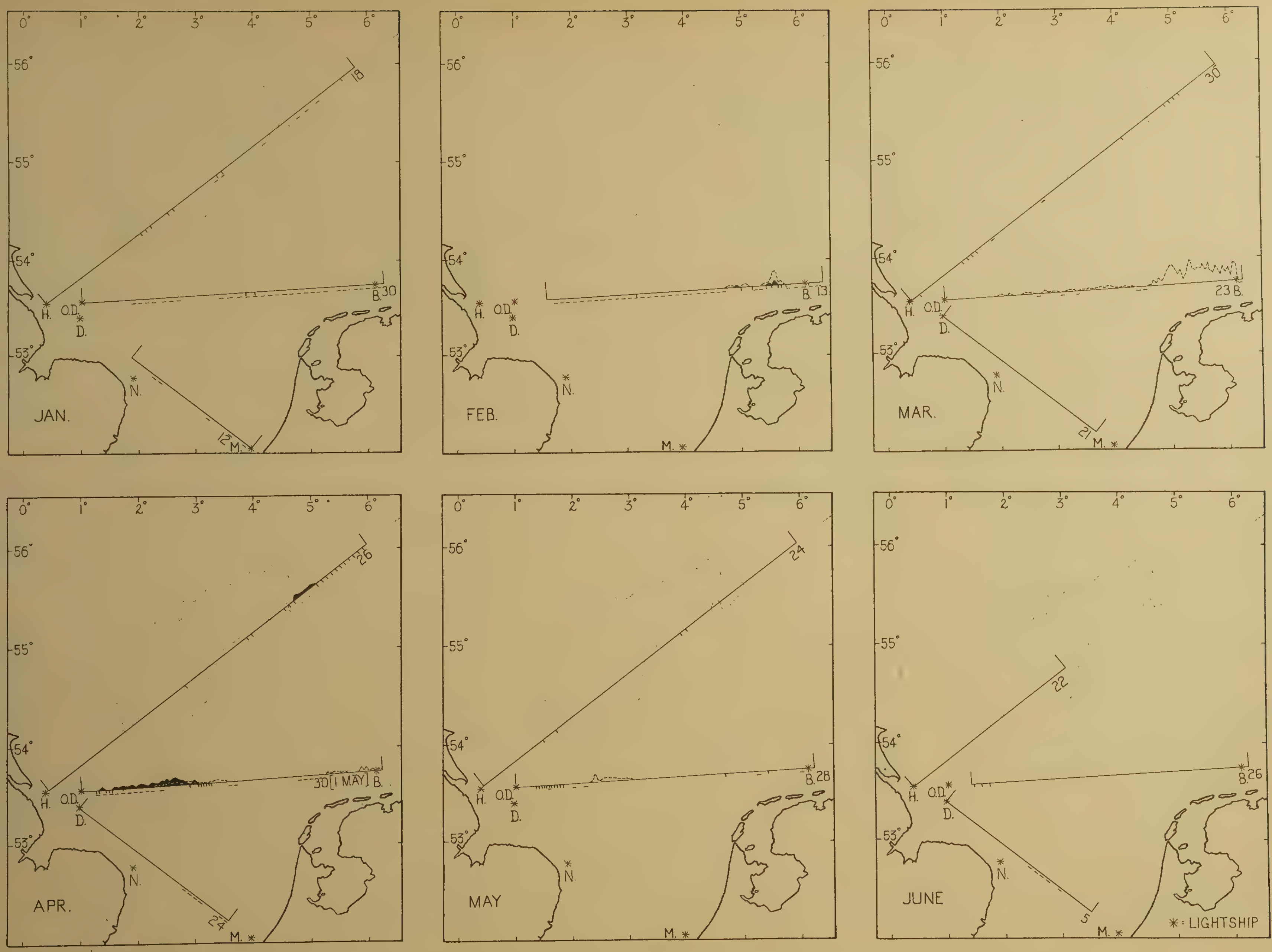

JAN.
FEB.
MAR.
APR.
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
20
11
24
17
22
28
27
13
19
23
6
✳ = LIGHTSHIP

RHIZOSOLENIA STYLIFORMIS (*blacked-in graph*) *and* **BIDDULPHIA SINENSIS** (*broken line*), 1934, *for further explanation see Plate* XXII.

PLATE XXVII

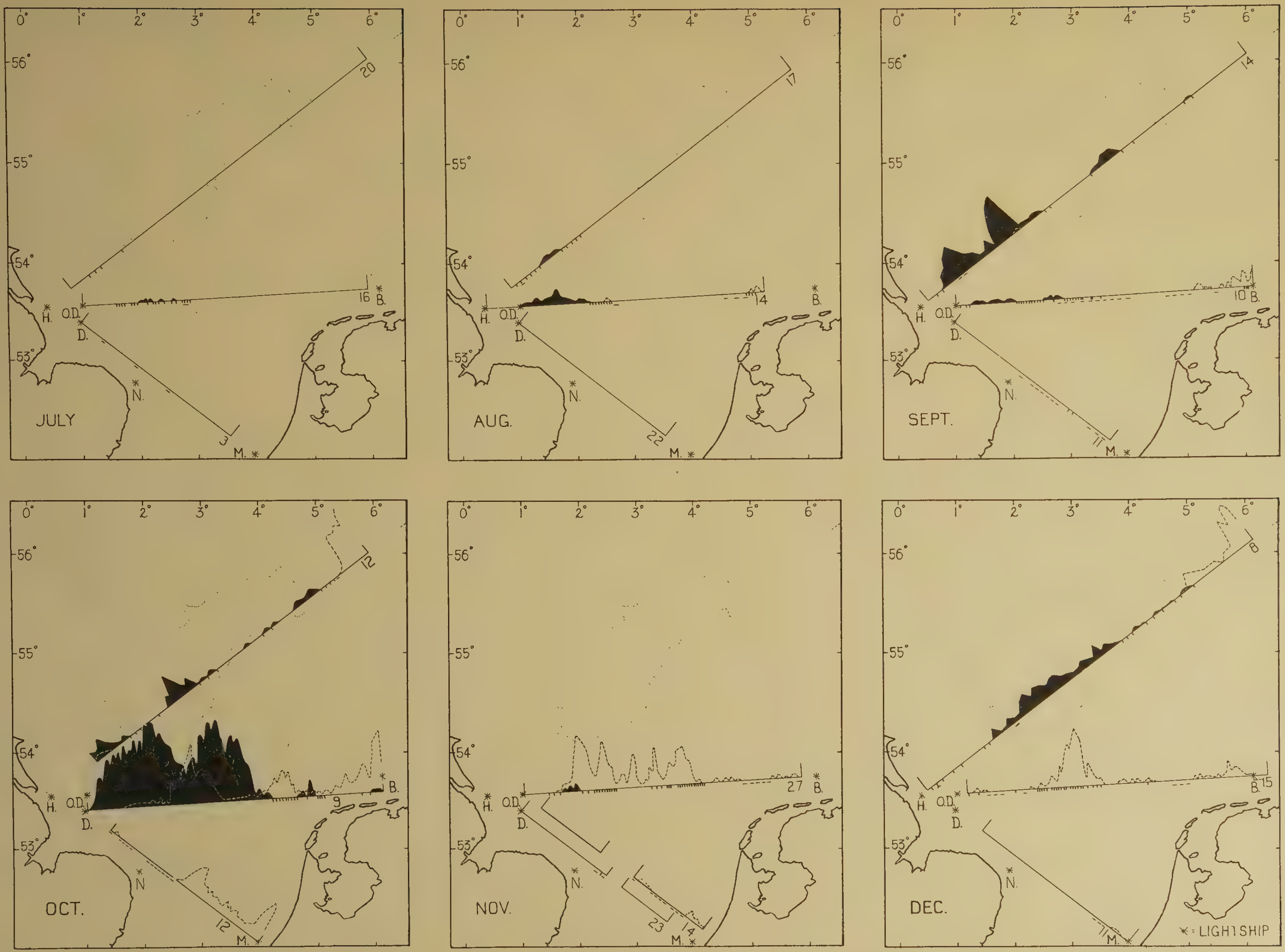

JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
H.
O.D.
D.
N.
M.
B.
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
21
27
31 (2 AUG)
18
25
29
19
13
11
10
17
15
4
*= LIGHTSHIP

RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1934, for further explanation see Plate XXII.*



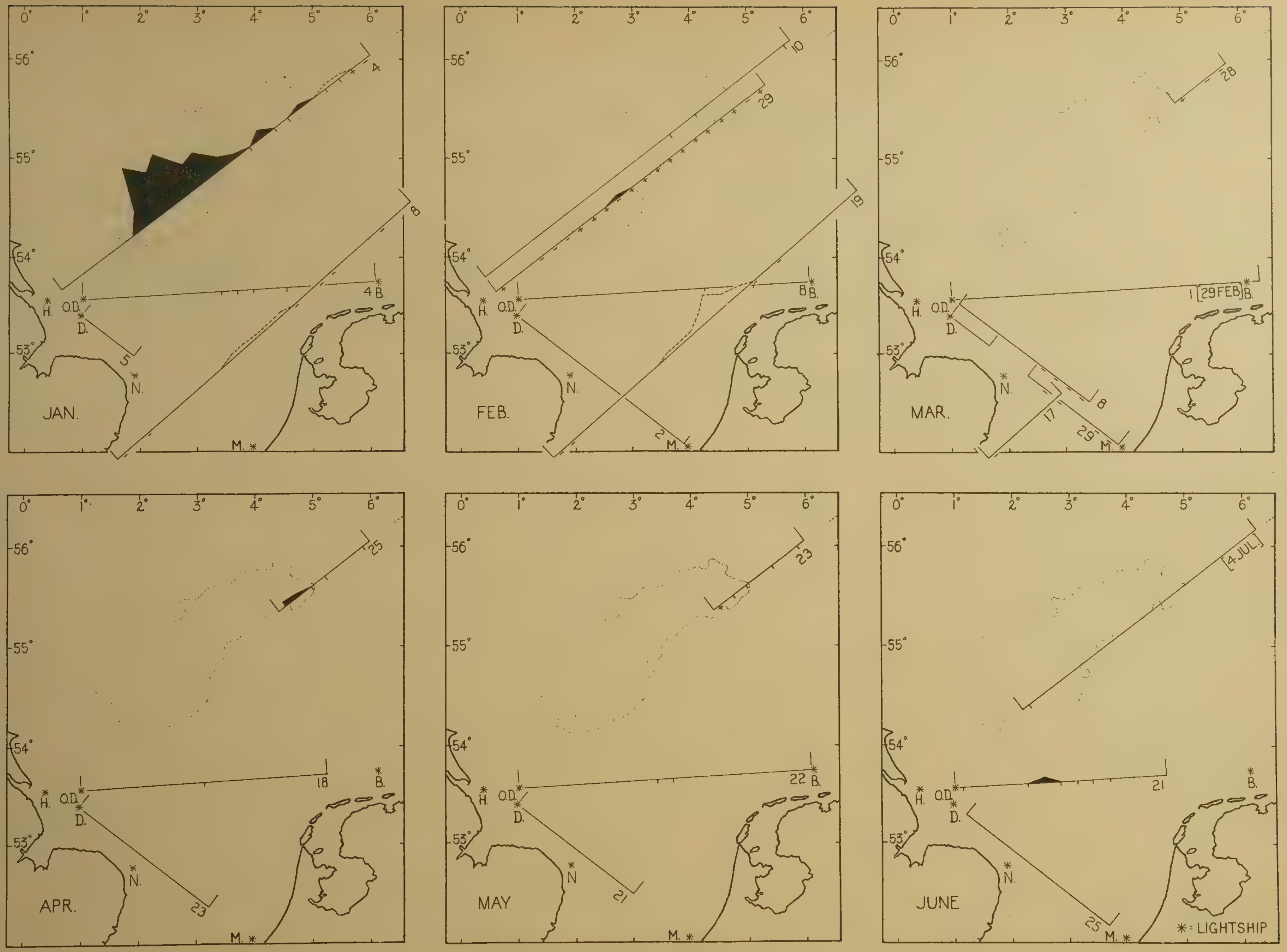
RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1935, for further explanation see Plate XXII.*

PLATE XXIX


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
H.
O.D.
D.
N.
M.
B.
20
16
3
17
14
22
14
10
11
12
9
12
27
23
14
8
15
11
✳ = LIGHTSHIP

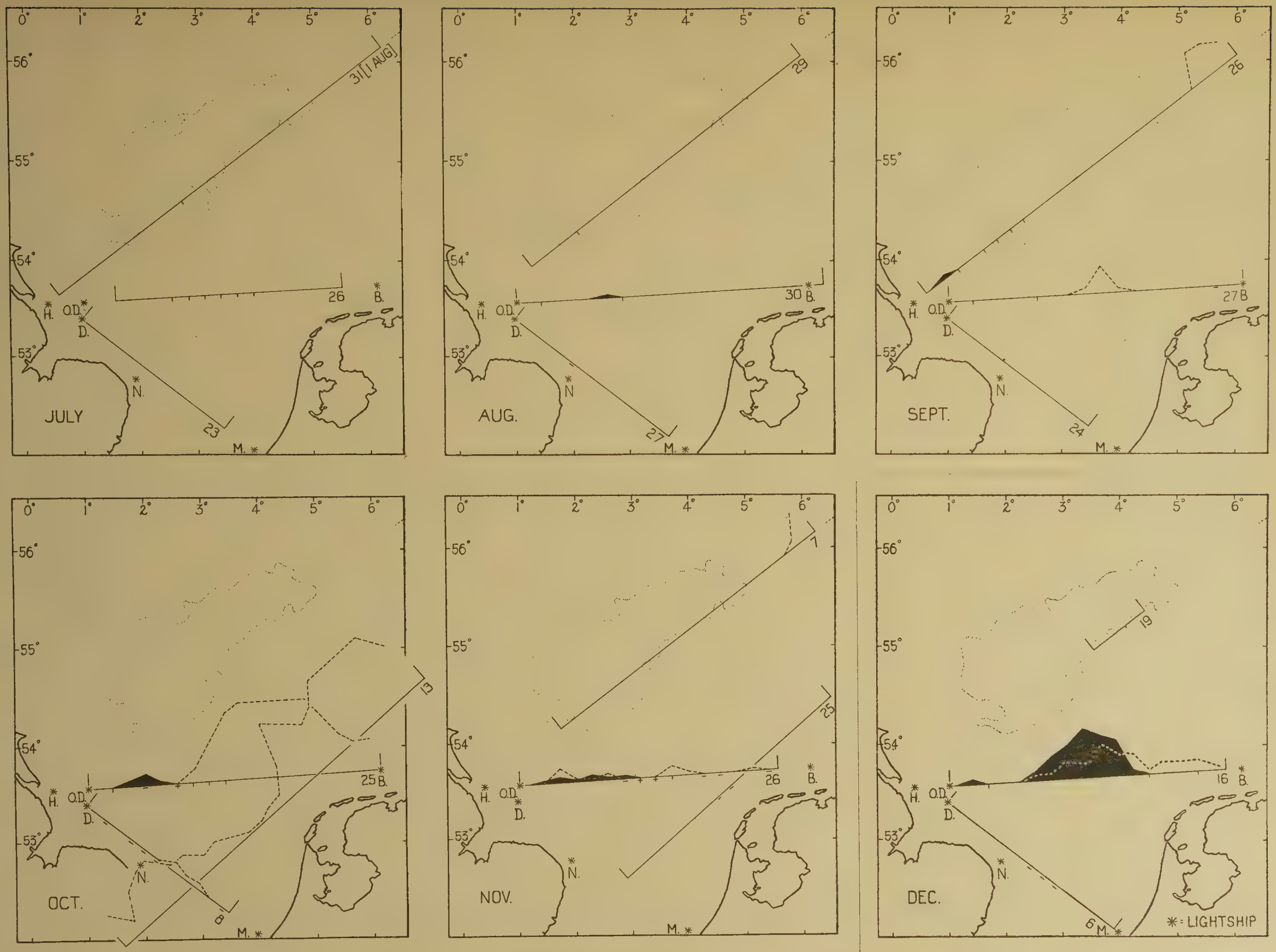
RHIZOSOLENIA STYLIFORMIS (*blacked-in graph*) *and* **BIDDULPHIA SINENSIS** (*broken line*), 1935, *for further explanation see Plate XXII. See also Plate XXXVI for supplementary maps.*

PLATE XXX


JAN.
FEB.
MAR.
APR.
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
4
8
5
10
29
19
2
1
29 FEB
17
28
25
18
23
22
21
4 JUL.
✱ = LIGHTSHIP

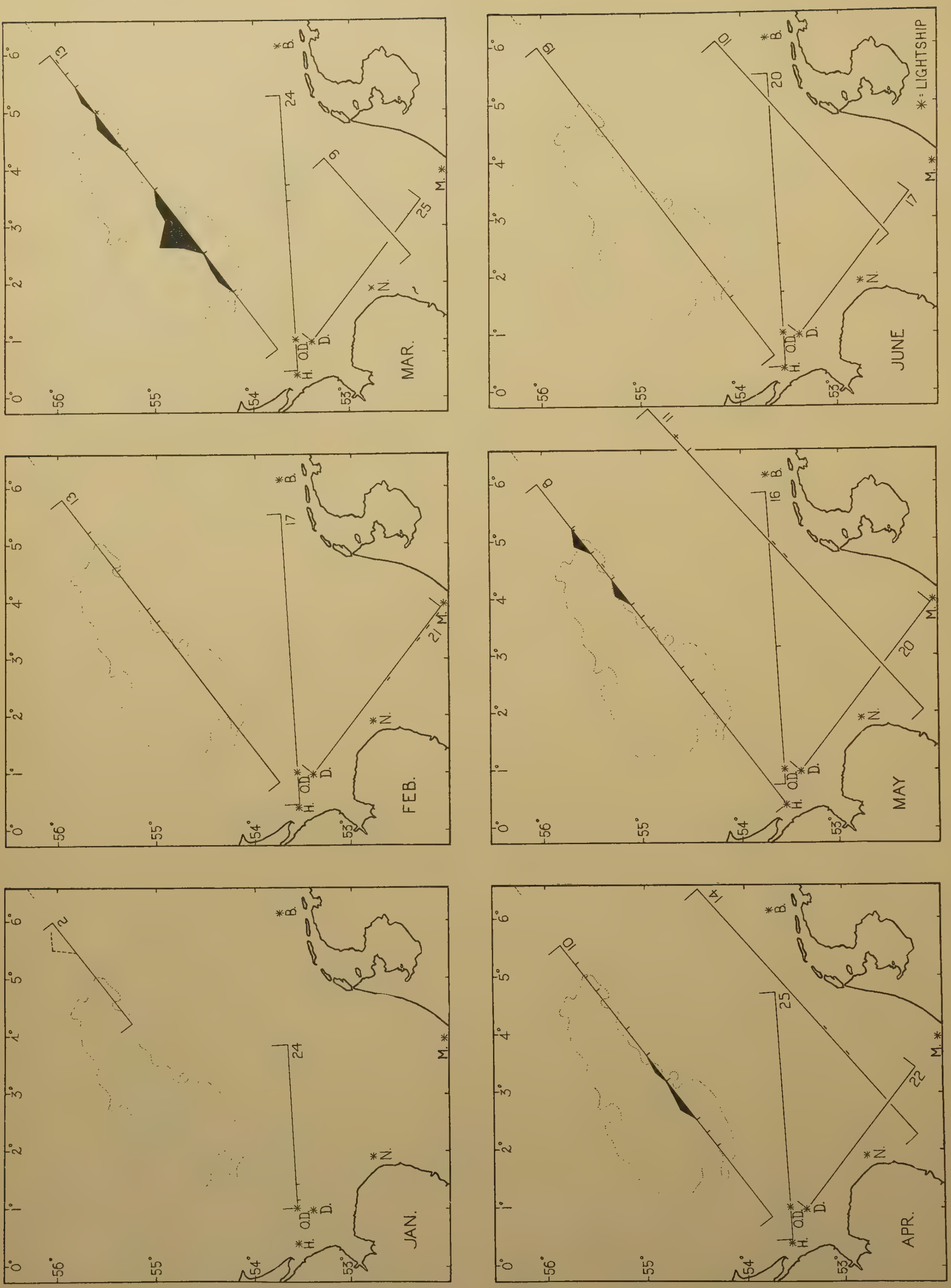
RHIZOSOLENIA STYLIFORMIS (*blacked-in graph*) *and* **BIDDULPHIA SINENSIS** (*broken line*), 1936, *for further explanation see Plate XXII.*

PLATE XXXI


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
JULY
31 [1 AUG]
26
23
AUG.
29
30
27
SEPT.
26
27 B
24
OCT.
13
25 B.
8
NOV.
1
25
26
DEC.
19
16
6
✱ = LIGHTSHIP

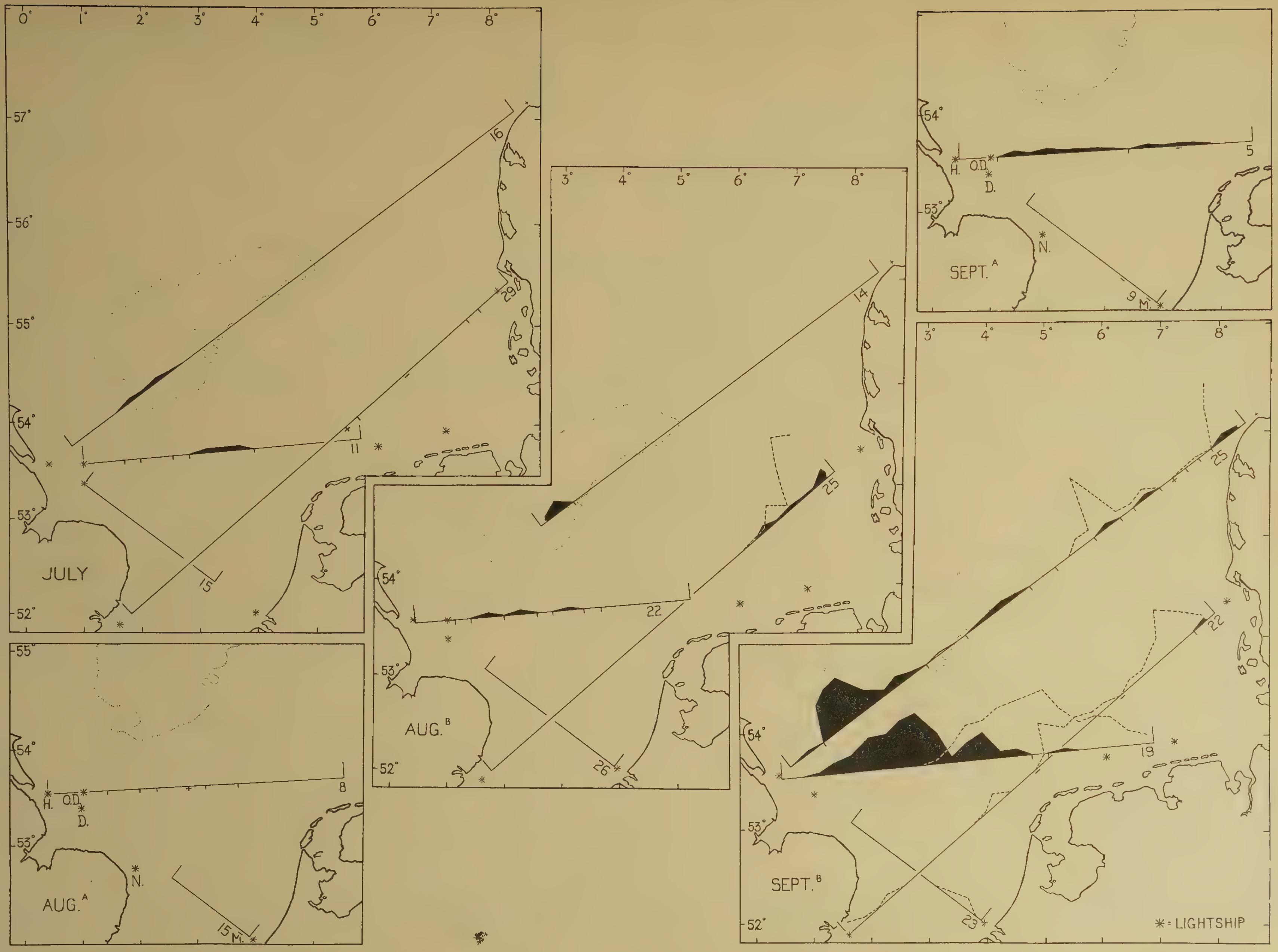
RHIZOSOLENIA STYLIFORMIS (*blacked-in graph*) *and* **BIDDULPHIA SINENSIS** (*broken line*), *1936, for further explanation see Plate XXII. See also Plate XXXVI for supplementary maps.*

PLATE XXXII


JAN.
FEB.
MAR.
APR.
MAY
JUNE
H.
O.D.
D.
N.
M.
B.
✱ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°

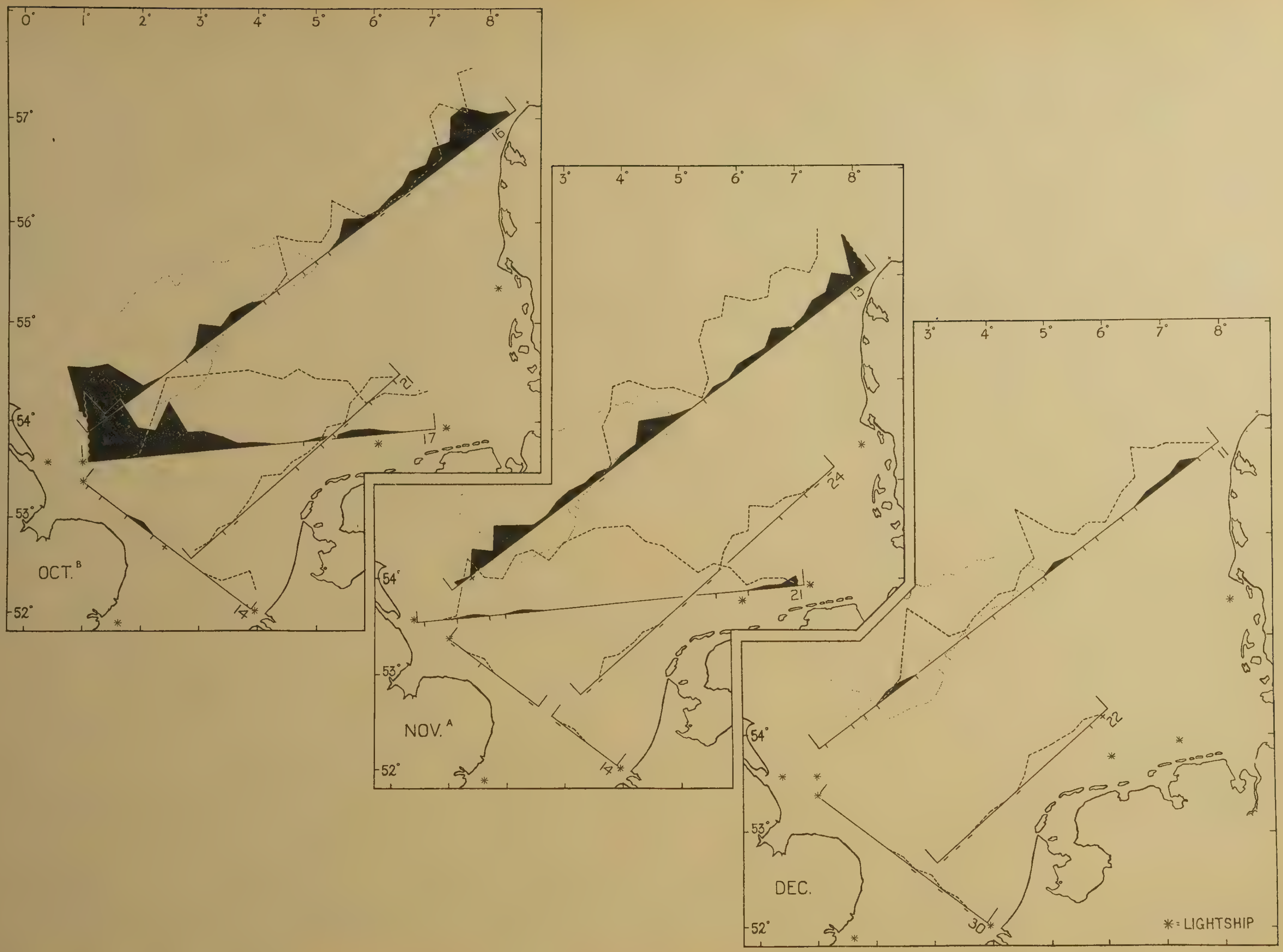
RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1937, for further explanation see Plate XXII.*

PLATE XXXIII


JULY
AUG. A
AUG. B
SEPT. A
SEPT. B
H.
O.D.
D.
N.
16
29
11
15
8
15 M.
14
25
22
26
5
9 M.
19
23
0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
✱ = LIGHTSHIP

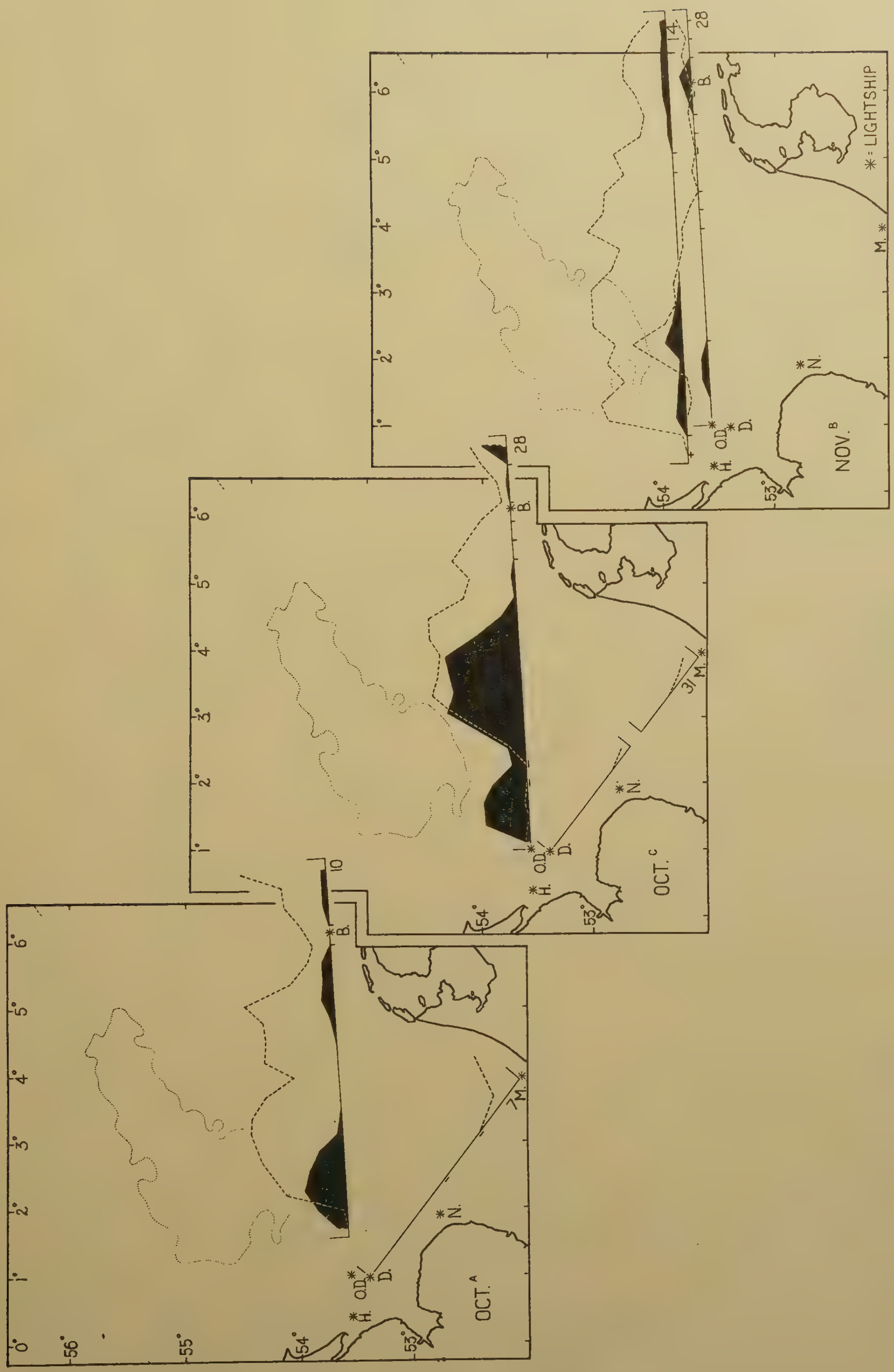
RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1937, and continued on Plates XXXIV and XXXV, for further explanation see Plate XXII.*

PLATE XXXIV


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
21
17
1
14
OCT.^B
13
24
21
14
NOV.^A
11
22
30
DEC.
✱ = LIGHTSHIP

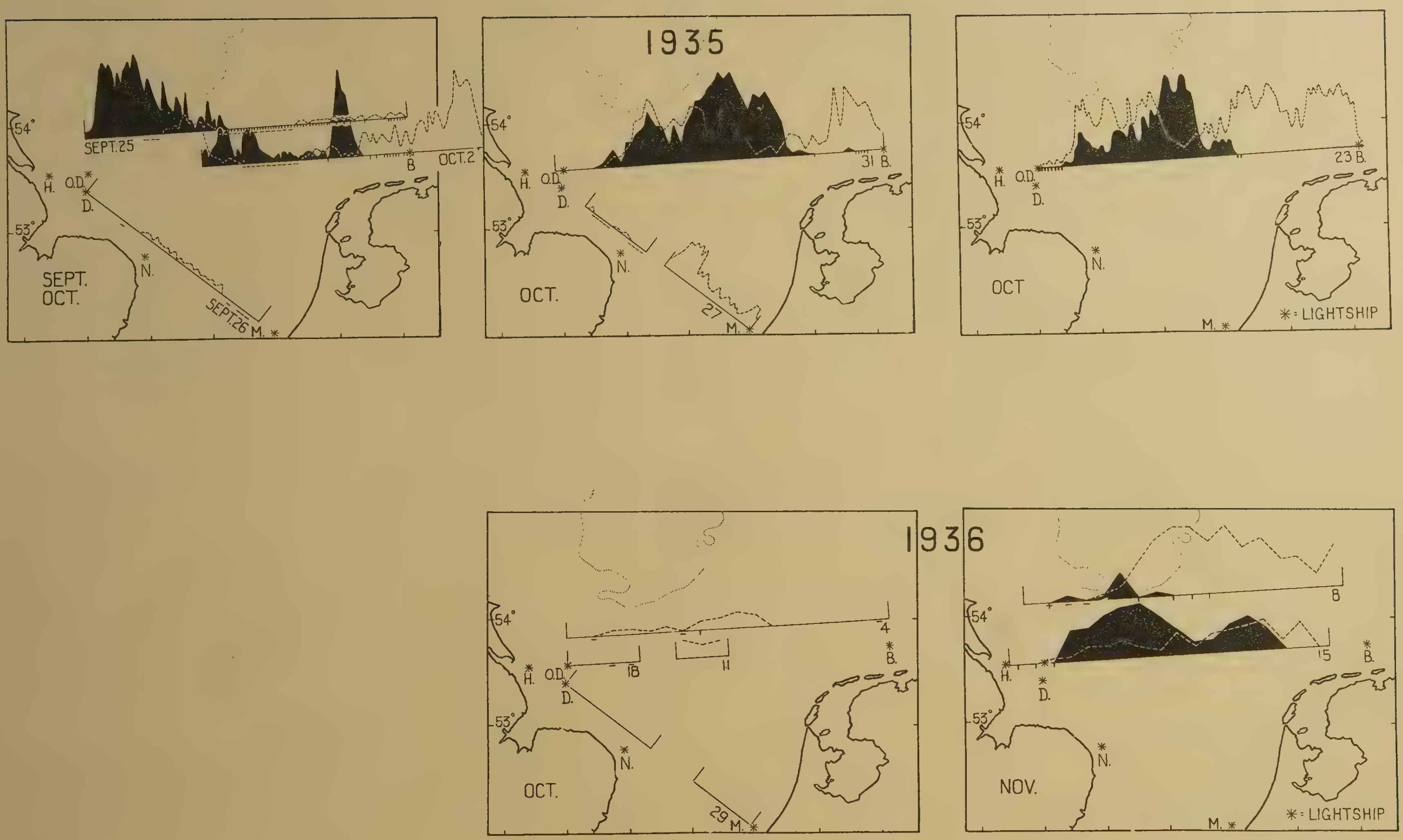
RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1937 continued, for further explanation see Plate XXII.*

PLATE XXXV


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
OCT. A
OCT. C
NOV. B
10
28
14
3
✱ = LIGHTSHIP

RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* **BIDDULPHIA SINENSIS** *(broken line), 1937 maps supplementary to Plate XXXIV.*

PLATE XXXVI


1935
54°
53°
H.
O.D.
D.
N.
M.
B
SEPT.25
OCT.2
SEPT.26
SEPT.
OCT.
31 B.
27
OCT.
23 B.
OCT
✱ = LIGHTSHIP
1936
4
B.
18
11
29
8
15
NOV.

RHIZOSOLENIA STYLIFORMIS *(blacked-in graph) and* ***BIDDULPHIA SINENSIS*** *(broken line), maps supplementary to Plates XXIX (1935) and XXXI (1936).*

Explanation of PLATES XXXVII—XLIV

showing the distribution of patches of **OTHER DIATOMS**, i.e., other than *RHIZOSOLENIA STYLIFORMIS and BIDDULPHIA SINENSIS*, during the period June 1932 to December 1937.

The lines have been divided into blocks of *ca.* 20 miles each and the presence of a patch or patches is denoted by the use of various letters signifying the different diatoms (see below).

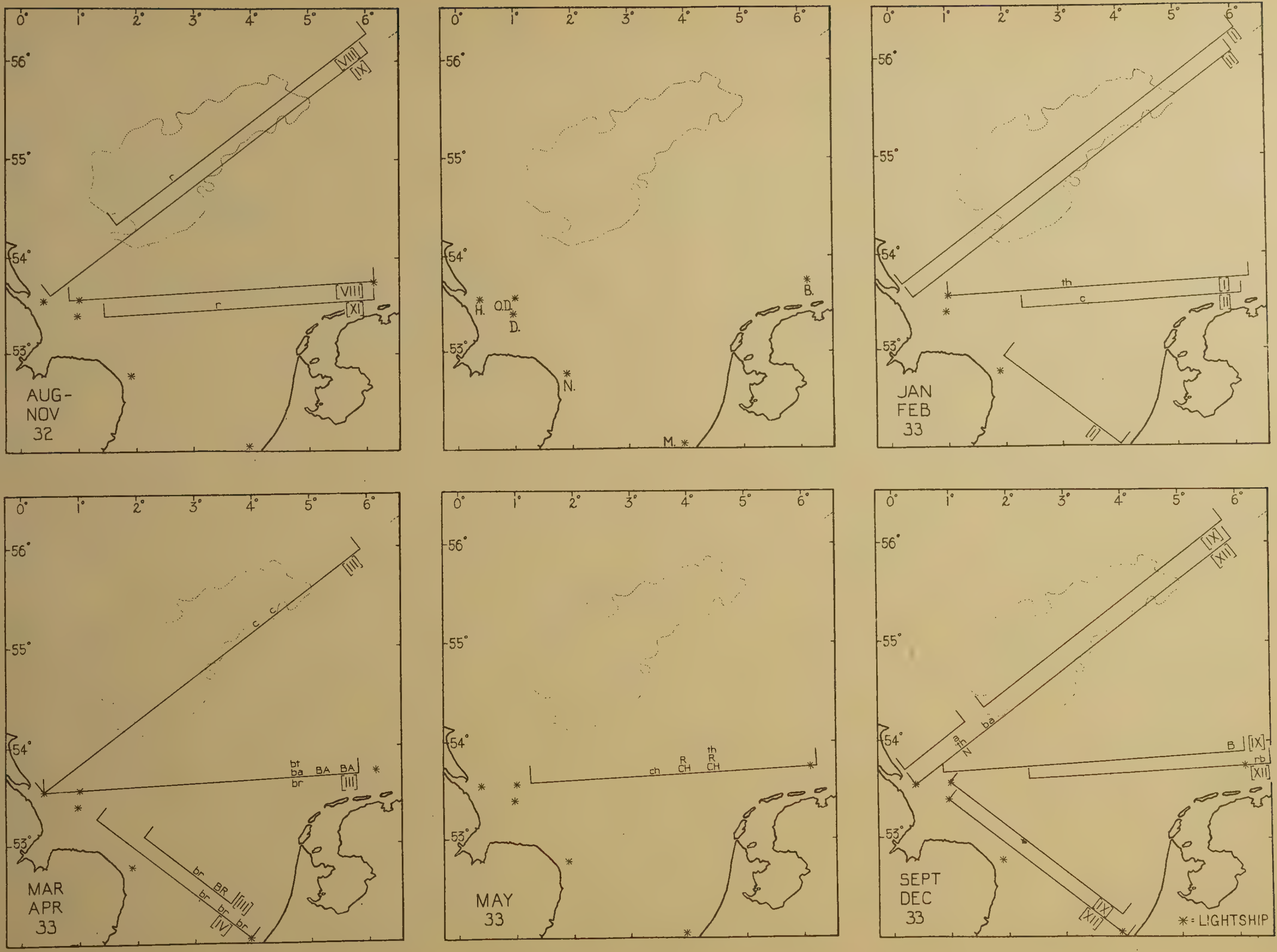
Only one comprehensive record will be shown for any month in which there has been more than one. For the later years the observations for all the months have been shown, but for space economy, only those months which provided patches have been shown for the earlier years (reference to previous plates will indicate which lines were sampled in any month not shown).

The following symbols are used for the different forms, capital letters indicating major patches and small letters intermediate patches (see text) :

A, a,	ASTERIONELLA
*B,	*BELLAROCHIA MALLEUS*
BA, ba,	*BIDDULPHIA AURITA*
BCA, bca,	*BACILLARIA PARADOXA*
BR, br,	*BIDDULPHIA REGIA* (etc.)
BRH. brh,	*BIDDULPHIA RHOMBUS*
BTM, btm,	BACTERIASTRUM
C, c,	COSCINODISCUS
CH, ch,	CHAETOCEROS
D, d,	*DYTILIUM BRIGHTWELLI*
G, g,	*GUINARDIA FLACCIDA*
L, l,	LEPTOCYLINDRUS
N, n,	NAVICULA (etc.)
R, r,	*RHIZOSOLENIA ALATA* and *SEMISPINA*
RB, rb,	*RH. SHRUBSOLEI*
RT, rt,	*RH. STOLTERFOTHII*
*S,	*SKELETONEMA COSTATUM*
Th, th,	THALASSIOSIRA (etc.)
TX, tx,	THALASSIOTHRIX
U, u,	*EUCAMPIA ZOODIACUS*

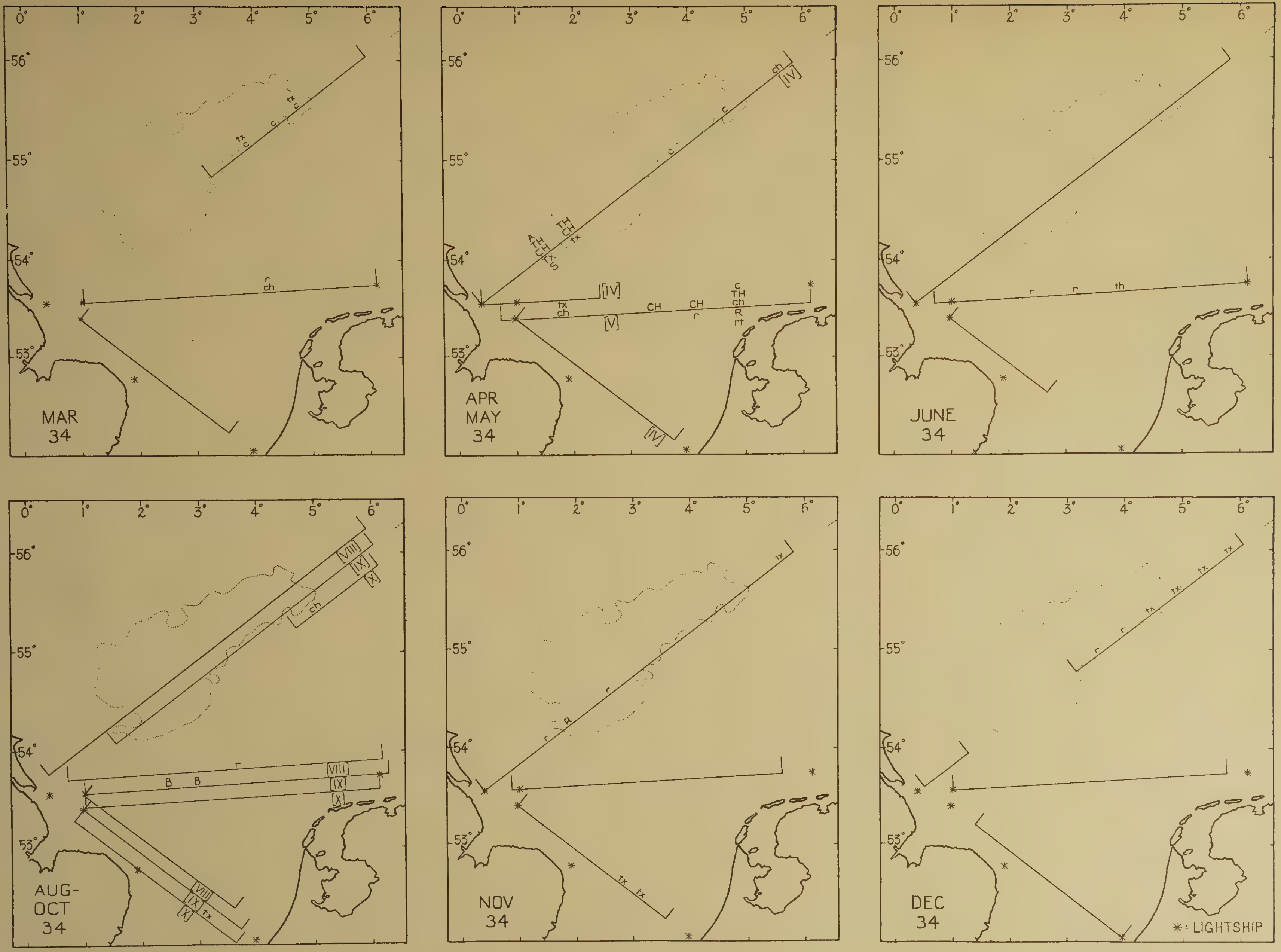
*Intermediate patches of BELLAROCHIA or SKELETONEMA have not been shown (see text).

PLATE XXXVII


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
AUG-
NOV
32
[VIII]
[IX]
[XI]
r
H.
O.D.
D.
N.
M.
B.
JAN
FEB
33
[I]
[II]
th
c
MAR
APR
33
[III]
[IV]
bt
ba
br
BA
BR
c
MAY
33
ch
R
CH
th
SEPT
DEC
33
[IX]
[XII]
B
rb
ba
an
N
✳ = LIGHTSHIP

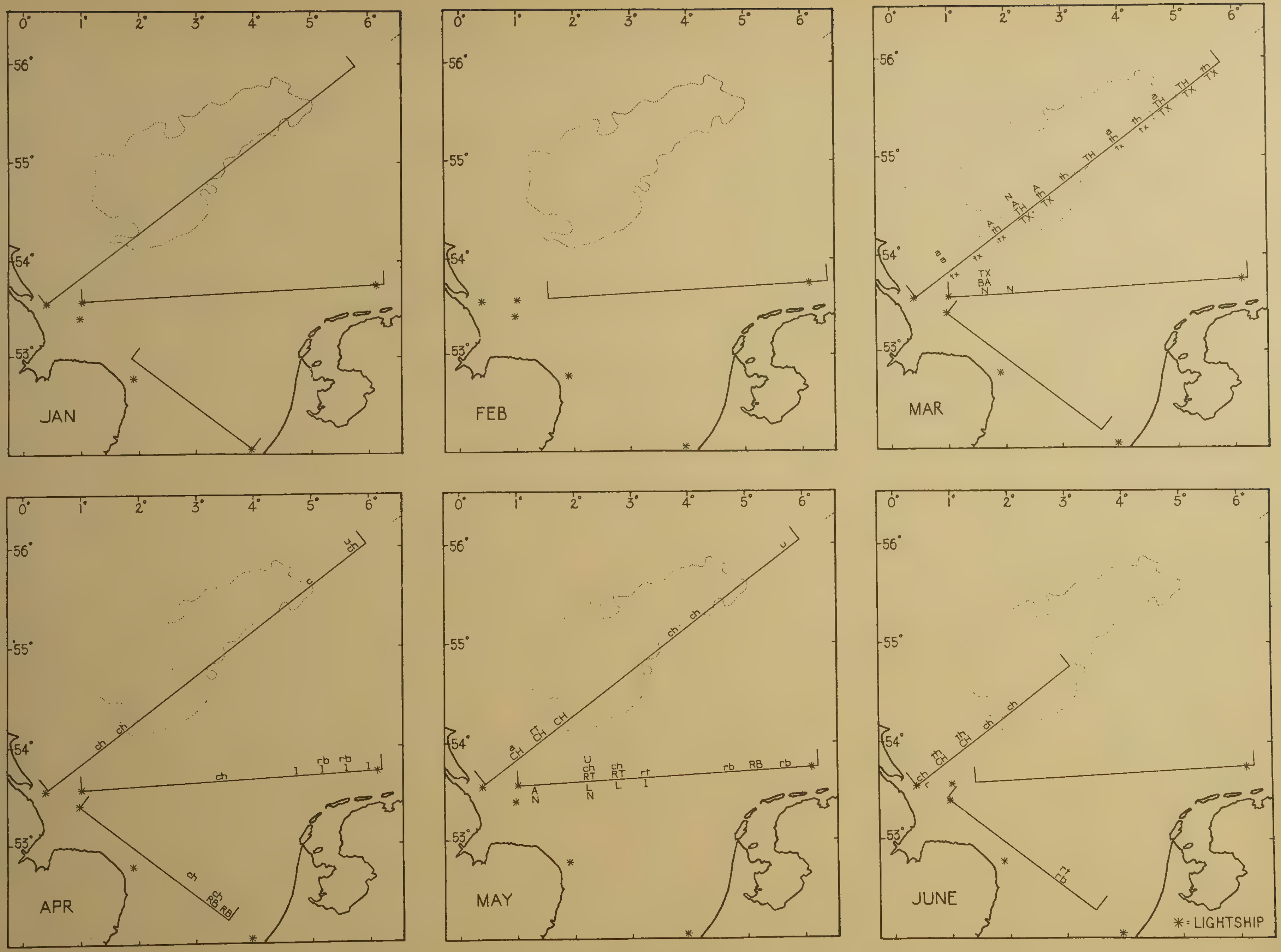
‘OTHER’ DIATOM *patches, 1932 and 1933, see explanation on preceding page.*

PLATE XXXVIII


MAR 34
APR MAY 34
JUNE 34
AUG-OCT 34
NOV 34
DEC 34
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
[IV]
[V]
[VIII]
[IX]
[X]
*: LIGHTSHIP

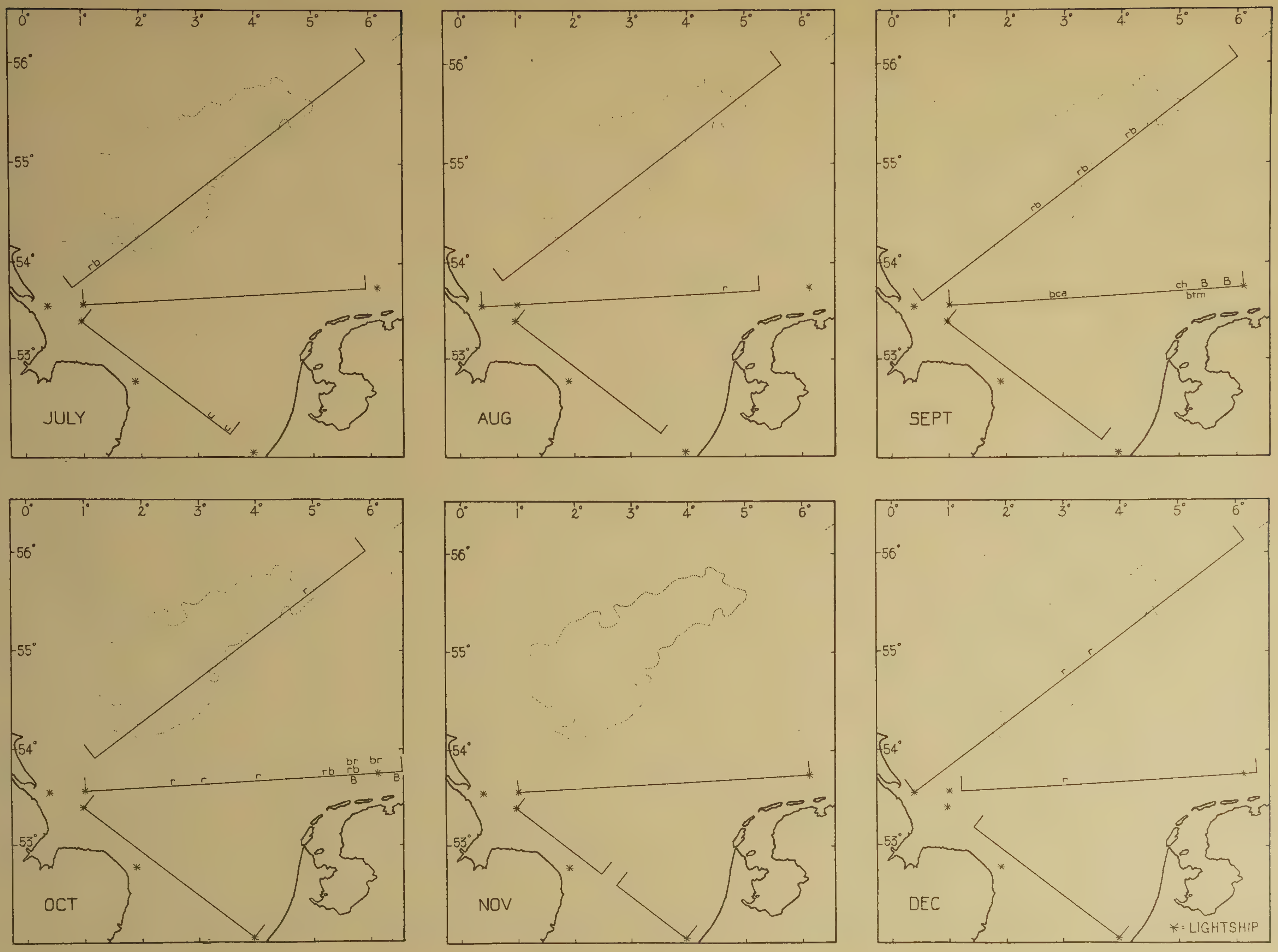
‘OTHER’ DIATOM *patches, 1934, see explanation preceding Plate XXXVII.*

PLATE XXXIX


JAN
FEB
MAR
APR
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
✳ = LIGHTSHIP

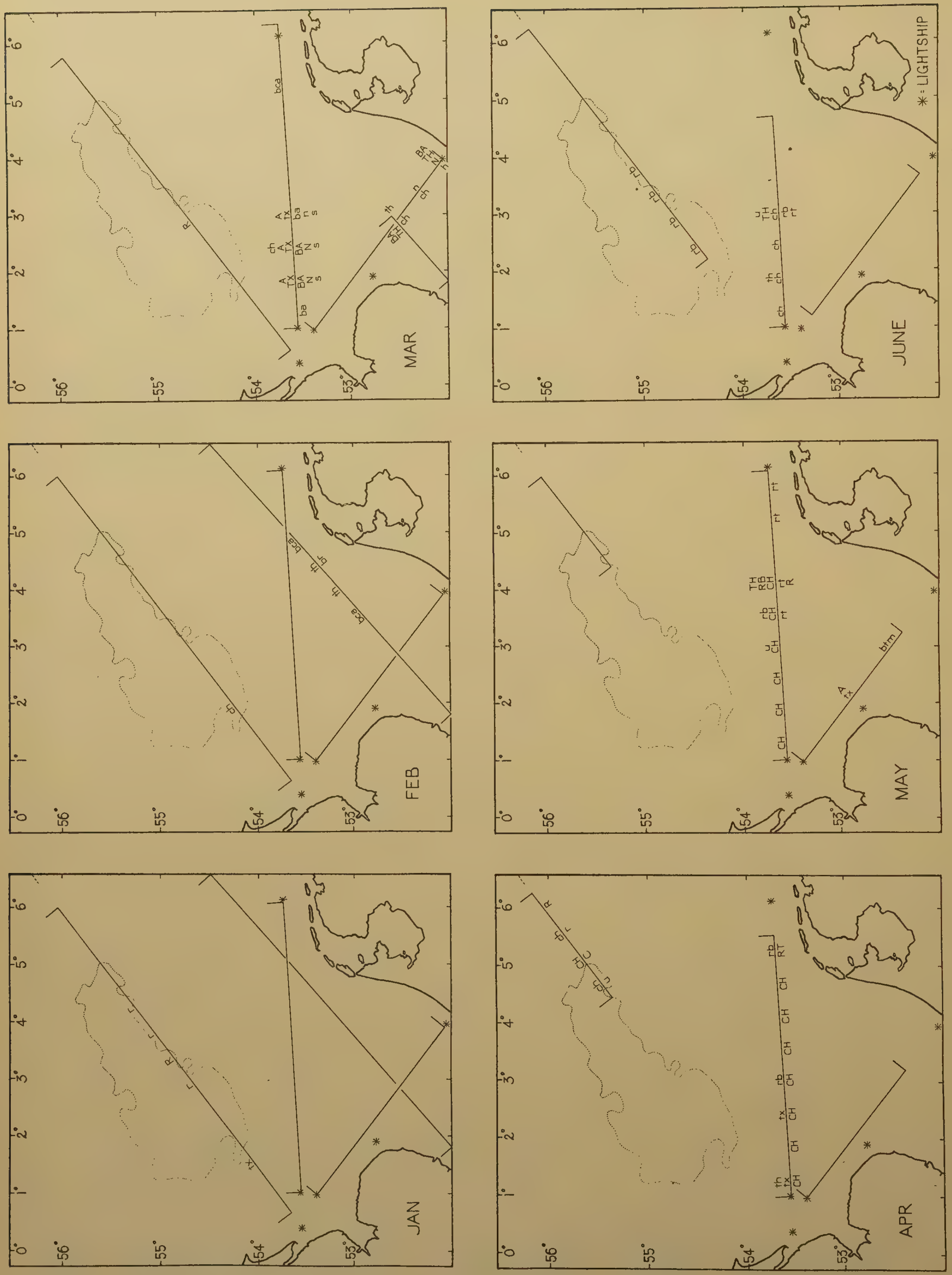
‘OTHER’ DIATOM *patches, 1935, see explanation preceding Plate XXXVII.*

PLATE XL


JULY
AUG
SEPT
OCT
NOV
DEC
✳ = LIGHTSHIP
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
rb
r
ch B B
btm
bca
br br
rb rb
B B

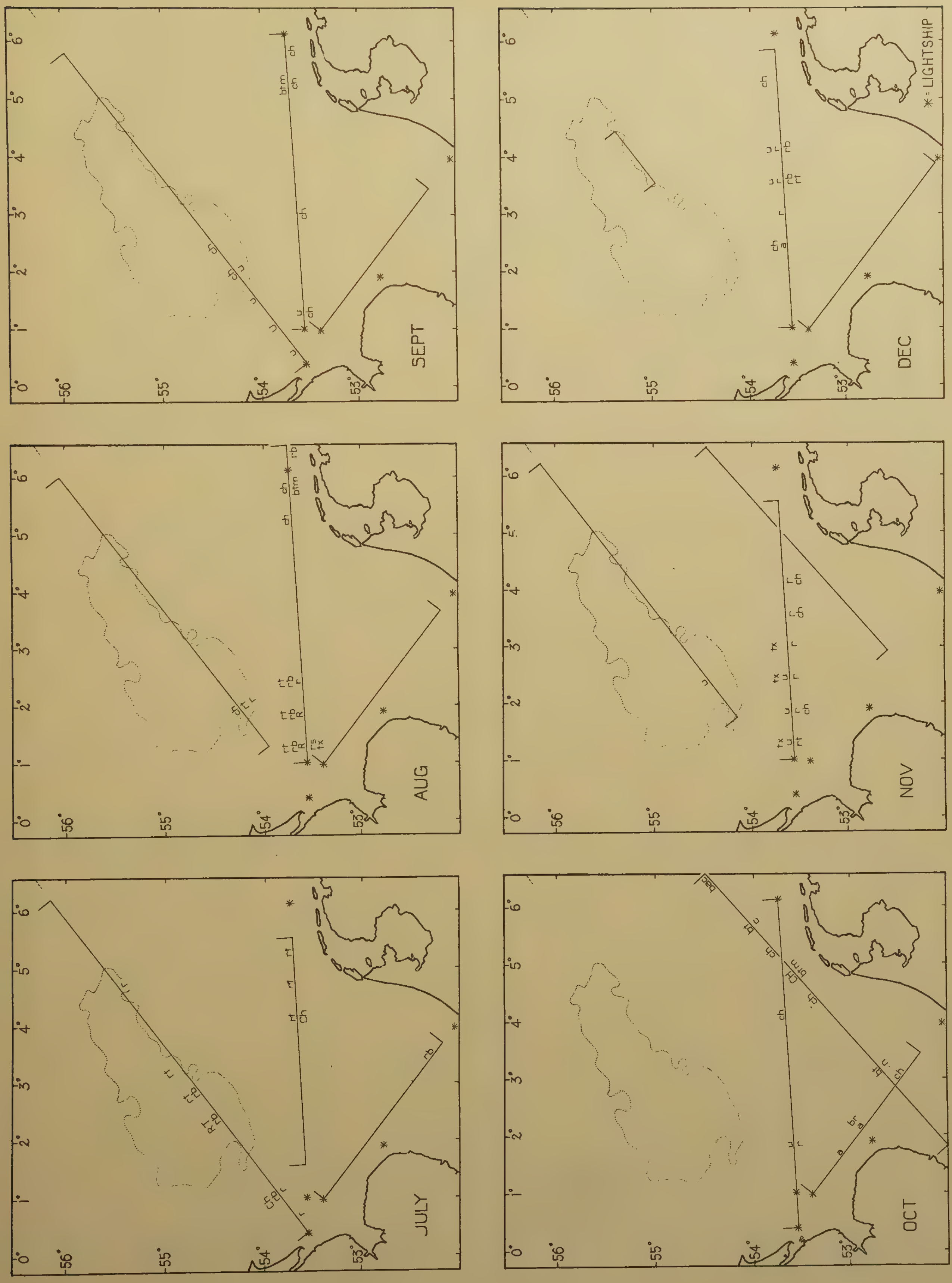
‘ OTHER ’ DIATOM *patches, 1935, see explanation preceding Plate XXXVII.*

PLATE XLI


JAN
FEB
MAR
APR
MAY
JUNE
✳ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°

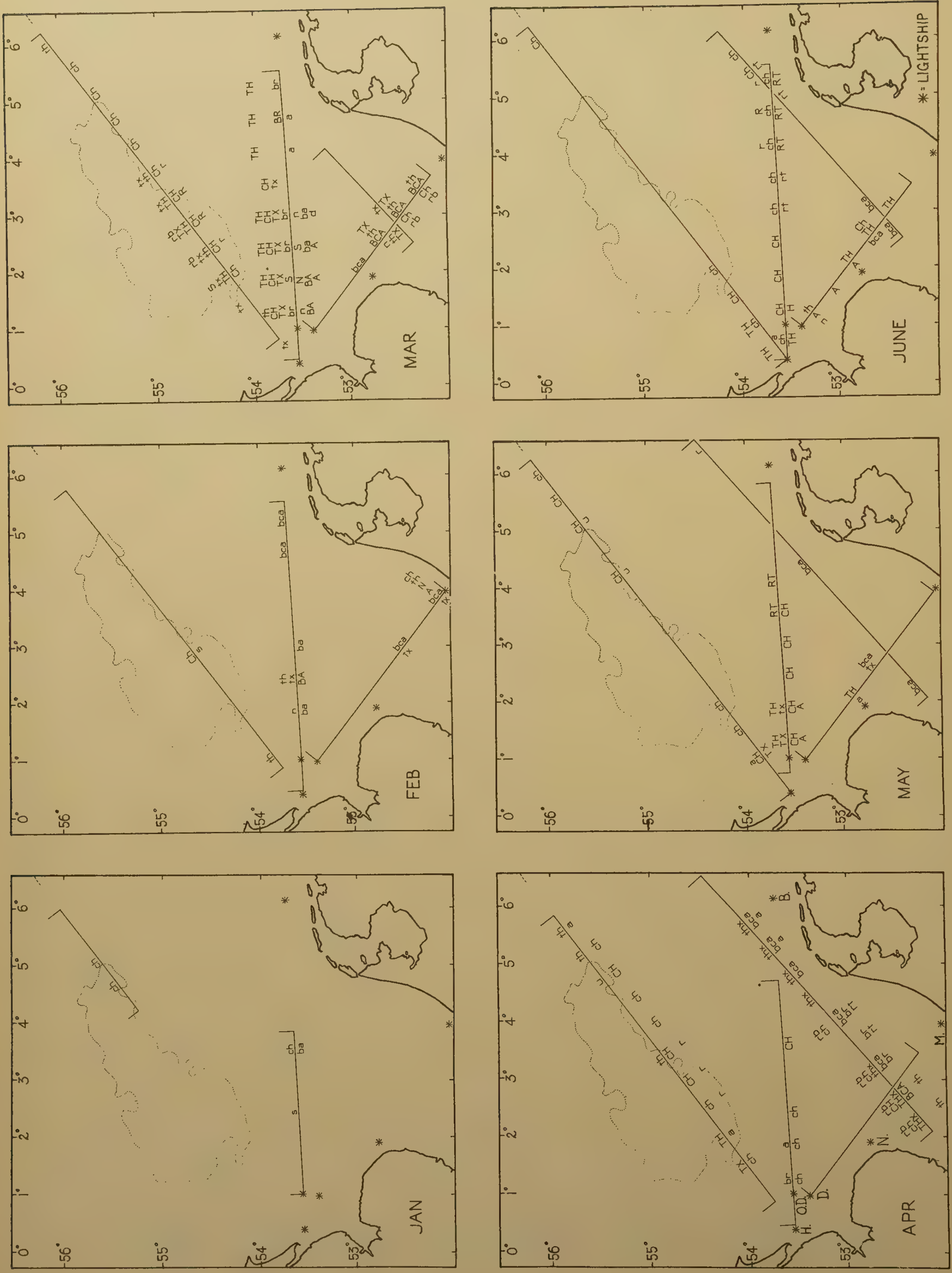
'OTHER' DIATOM *patches, 1936, see explanation preceding Plate XXXVII.*

PLATE XLII


JULY
AUG
SEPT
OCT
NOV
DEC
✳ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
ch
rt
rb
r
u
tx
btm
bac
br
a

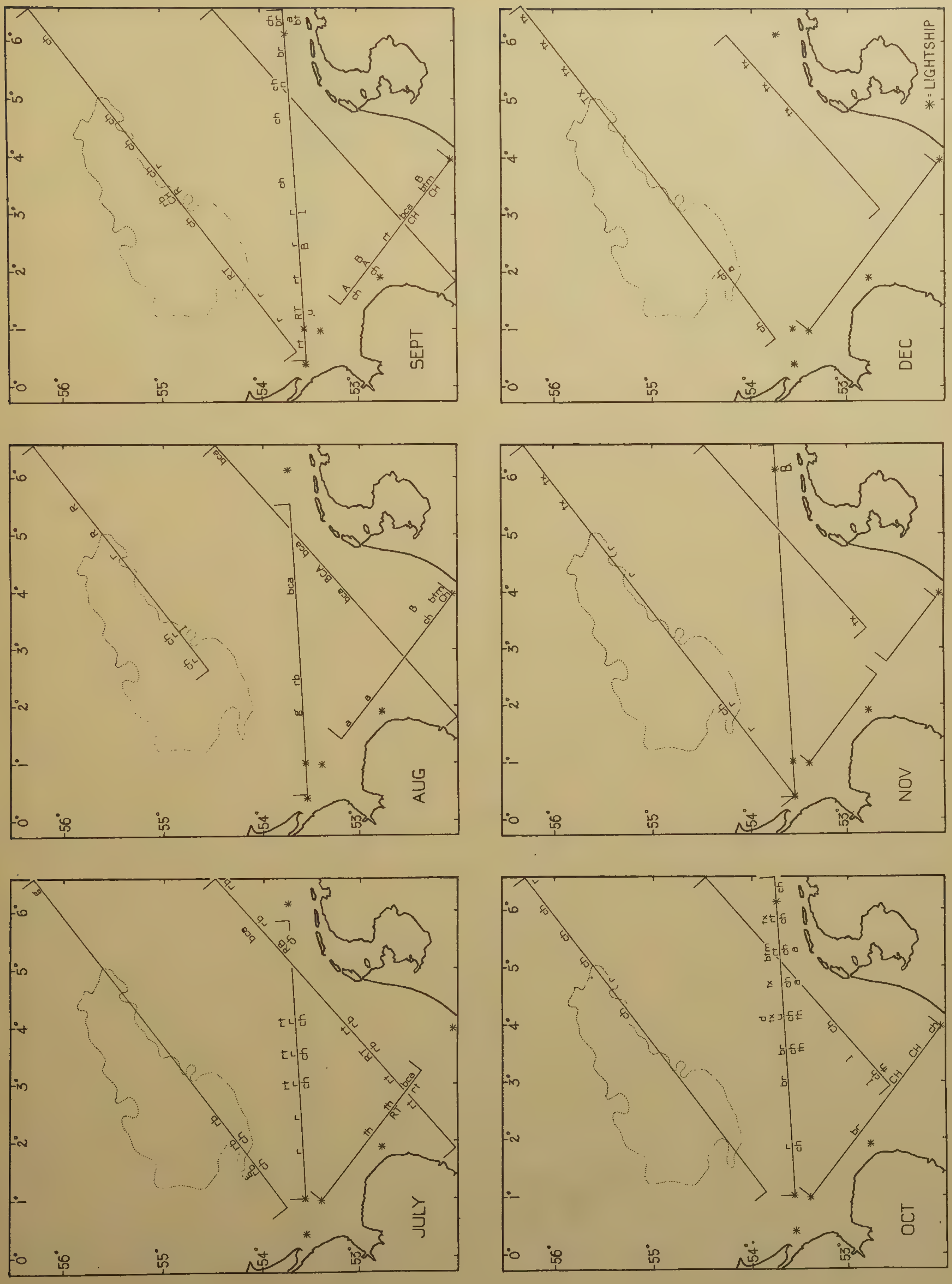
‘OTHER’ DIATOM *patches, 1936, see explanation preceding Plate XXXVII.*

PLATE XLIII


JAN
FEB
MAR
APR
MAY
JUNE
✱ = LIGHTSHIP
H.
O.D.
D.
N.
M.
B.
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°

'OTHER' DIATOM *patches, 1937, see explanation preceding Plate XXXVII.*

PLATE XLIV


JULY
AUG
SEPT
OCT
NOV
DEC
✱ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°

'OTHER' DIATOM *patches, 1937, see explanation preceding Plate XXXVII.*

The following Explanation applies to PLATES XLV–LVII

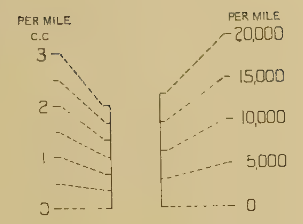
This series of maps has been prepared to show the distribution of the **DINOFLAGELLATES** and **PHAEOCYSTIS** in the southern North Sea month by month from June 1932 to December 1937. When more than one record have been obtained on one line in any month they have been included where possible ; others omitted will be found on Plates XI, XII and XV and text-figure 17.

The DINOFLAGELLATES are shown as blacked-in graphs and PHAEOCYSTIS as broken line graphs. Other details as explained on Plate XXII.

The first records, for June 1932, are shown in the map on the right.

PLATE XLV

Scale for
Plates XLV—LVII :


PER MILE
C.C
3
2
1
0
PER MILE
20,000
15,000
10,000
5,000
0

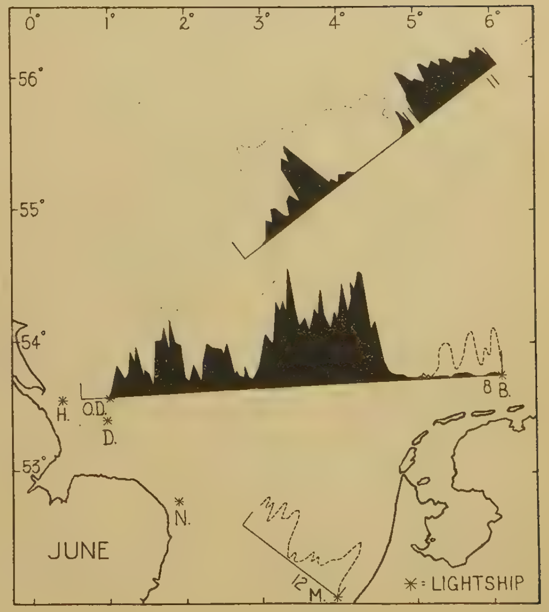
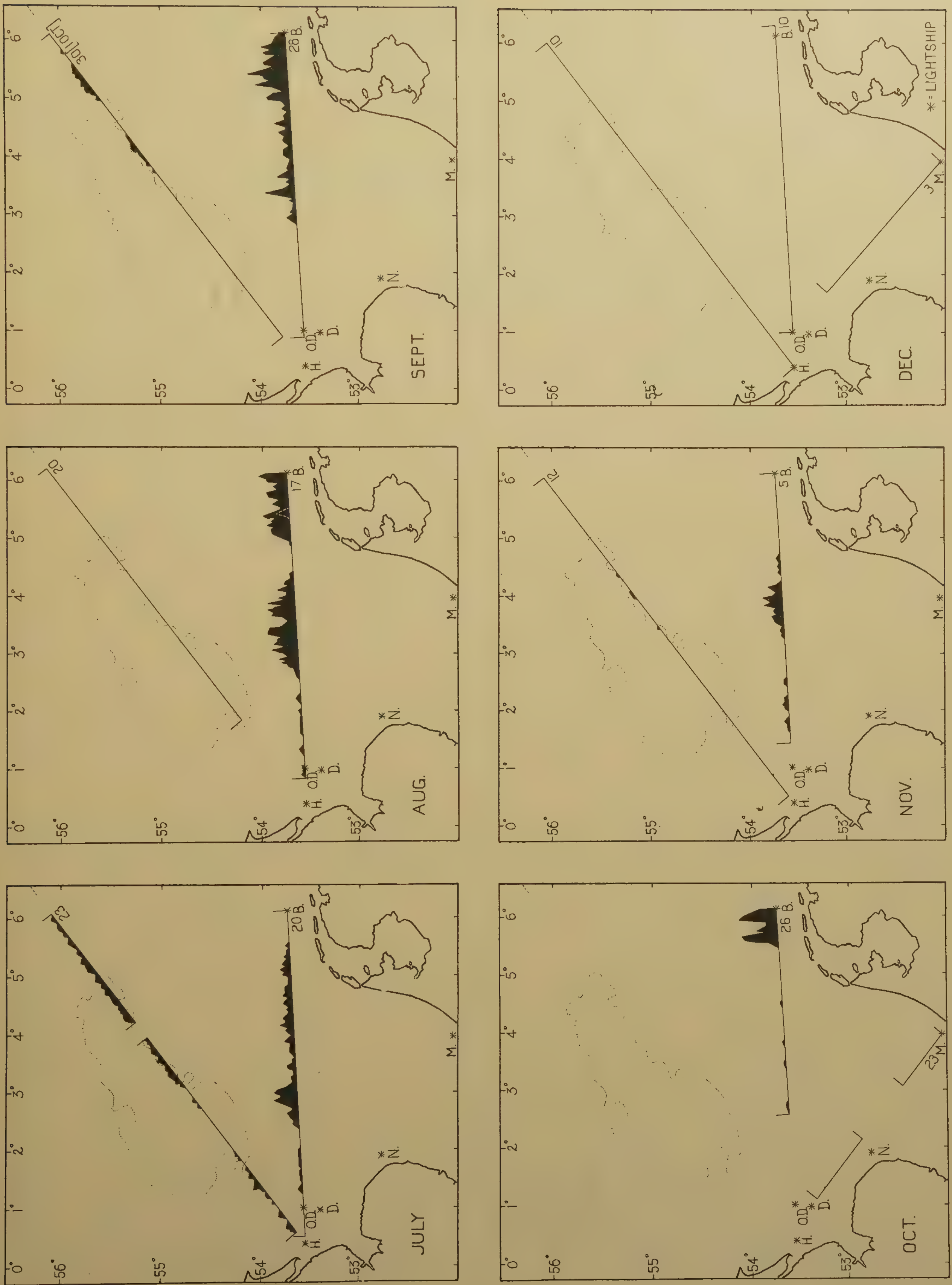
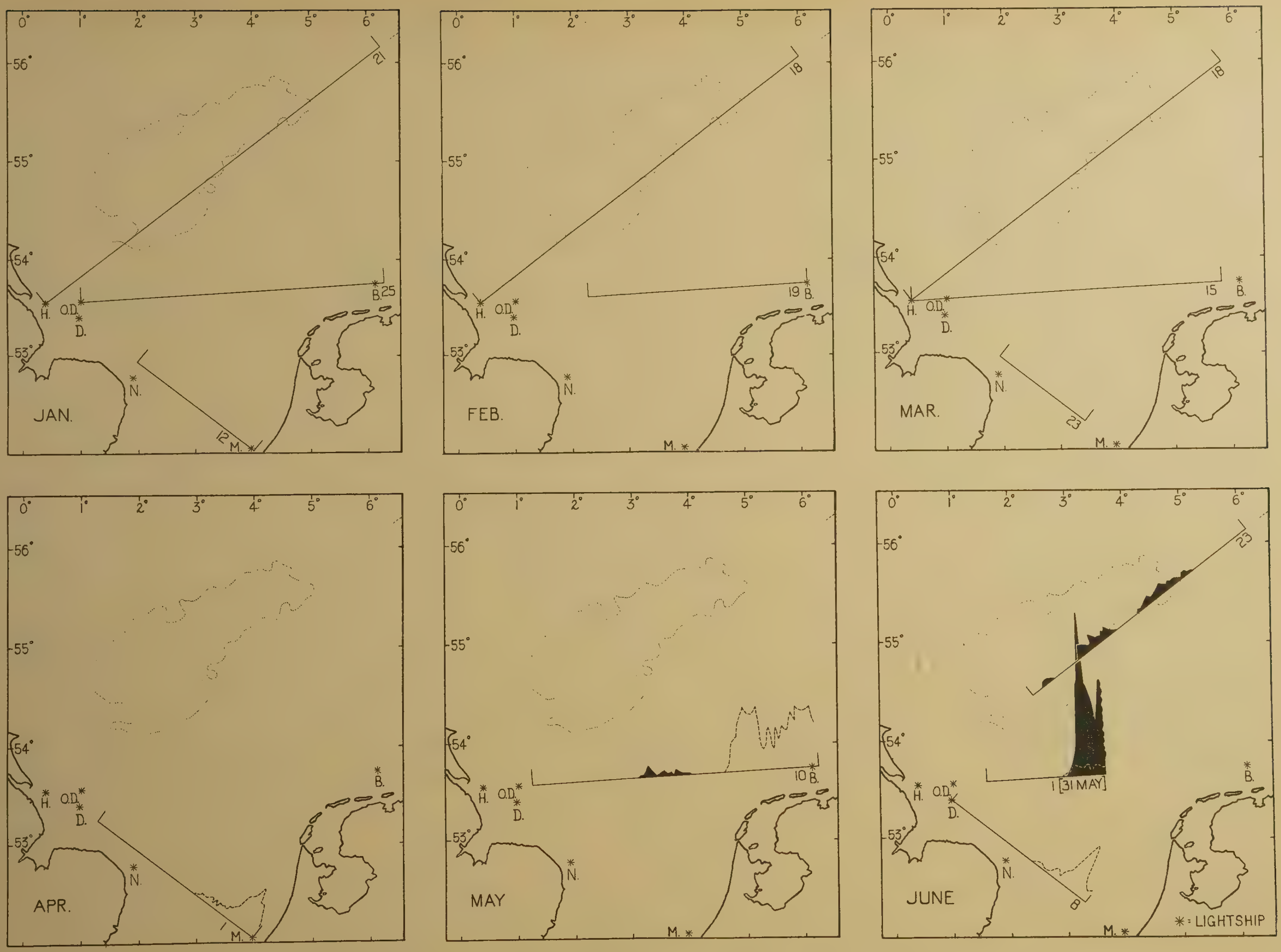

0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
8 B.
N.
12 M.
JUNE
✱ = LIGHTSHIP

PLATE XLVI


JULY
20 B.
23
AUG.
17 B.
20
SEPT.
28 B.
30 (OCT.)
OCT.
26 B.
23 M.
NOV.
5 B.
12
DEC.
B. 10
10
3 M.
H.
O.D.
D.
N.
M.
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
* = LIGHTSHIP

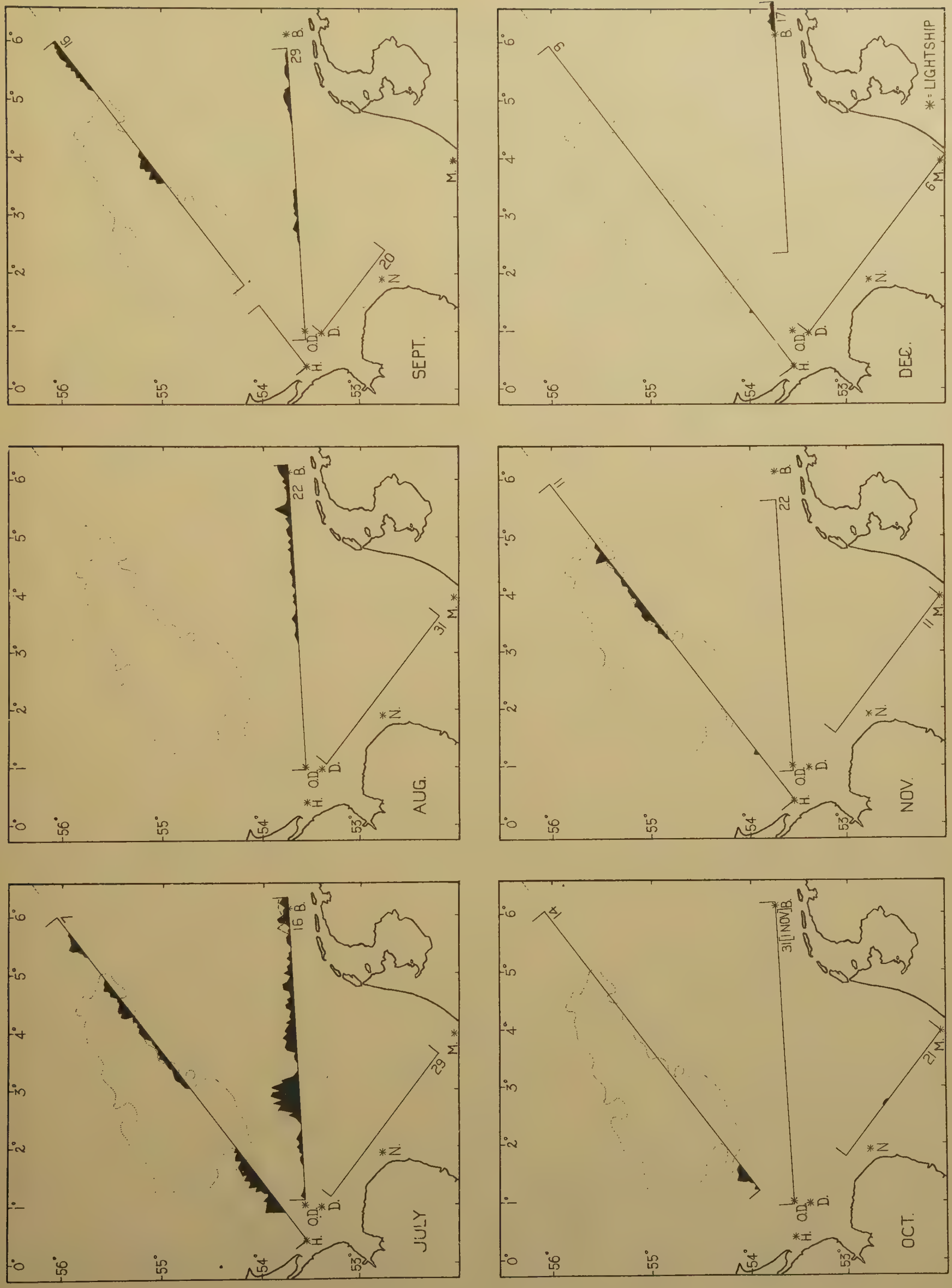
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line)*, 1932, *see explanation on Plate XLV.*

PLATE XLVII


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
JAN.
21
25
12
FEB.
18
19
MAR.
18
15
23
APR.
1
MAY
10
JUNE
23
1 [31 MAY]
8
✻ = LIGHTSHIP

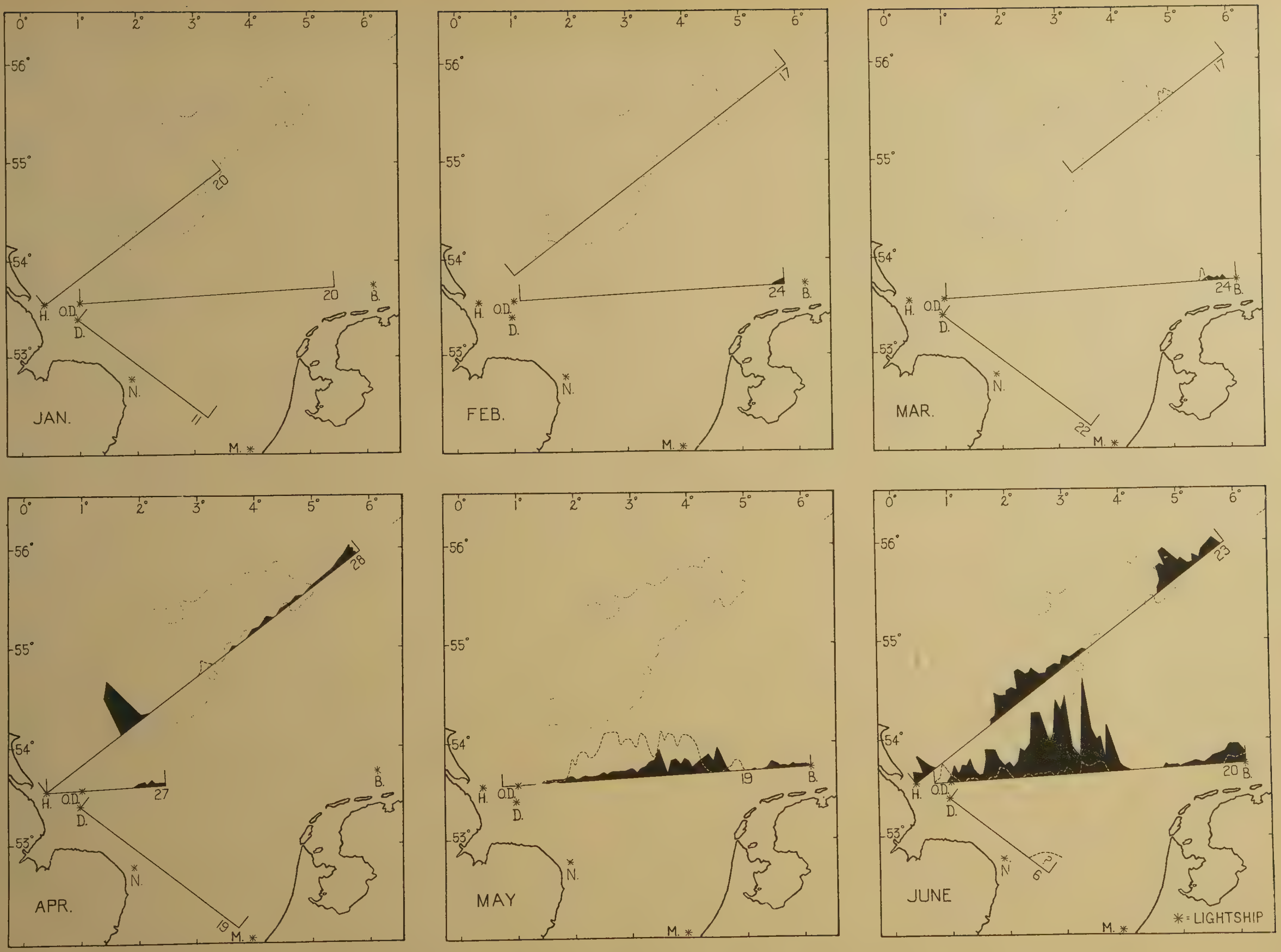
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1933, see explanation on Plate XLV.*

PLATE XLVIII


JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
56°
55°
54°
53°
0°
1°
2°
3°
4°
5°
6°
H.
O.D.
D.
N.
M.
B.
29
16
31
22
20
14
31|1 NOV.|B.
21
11
6
17
✱ = LIGHTSHIP

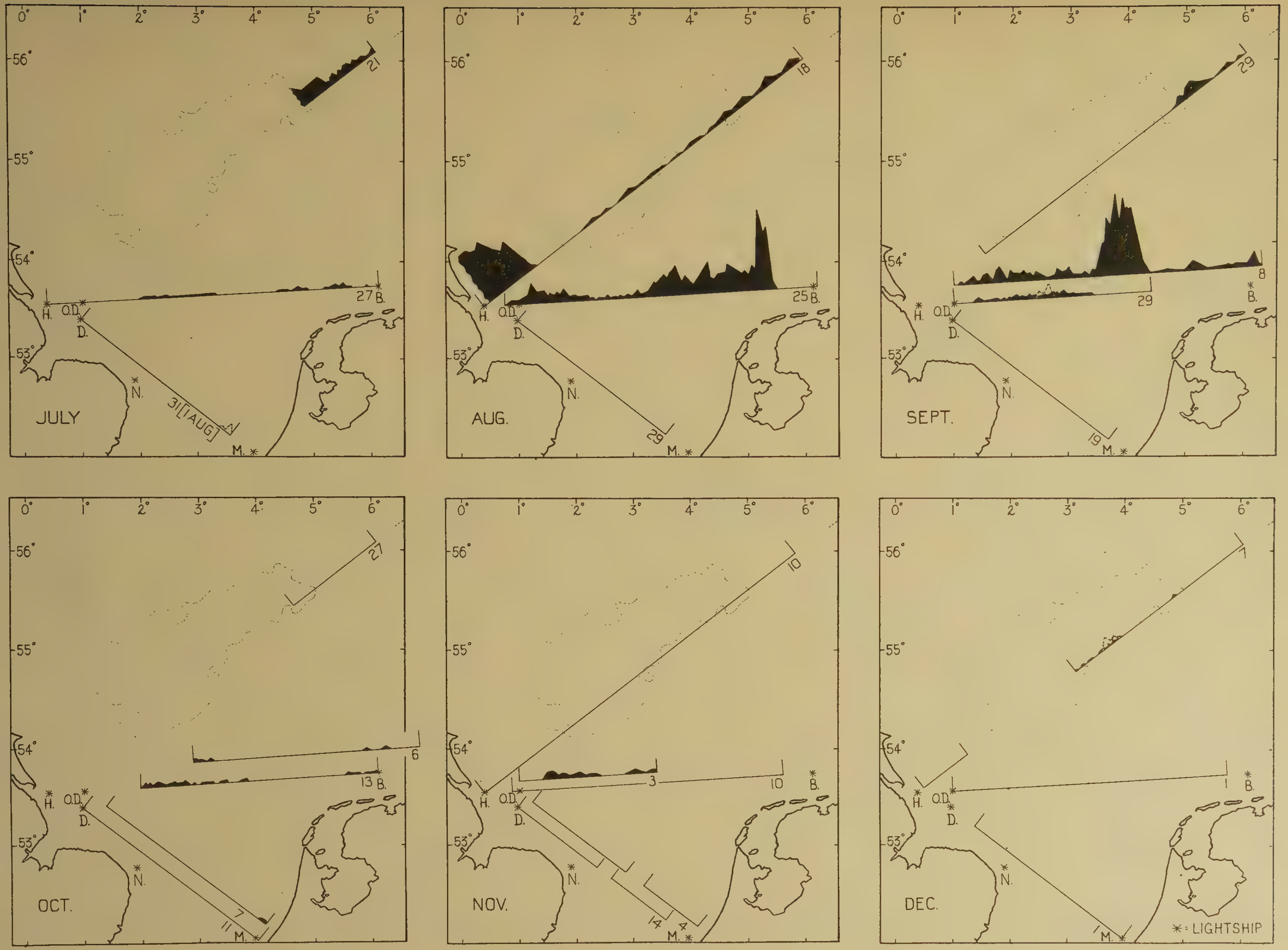
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1933, see explanation on Plate XLV.*

PLATE XLIX


JAN.
FEB.
MAR.
APR.
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
20
11
24
17
22
28
27
19
23
6
?
✱ = LIGHTSHIP

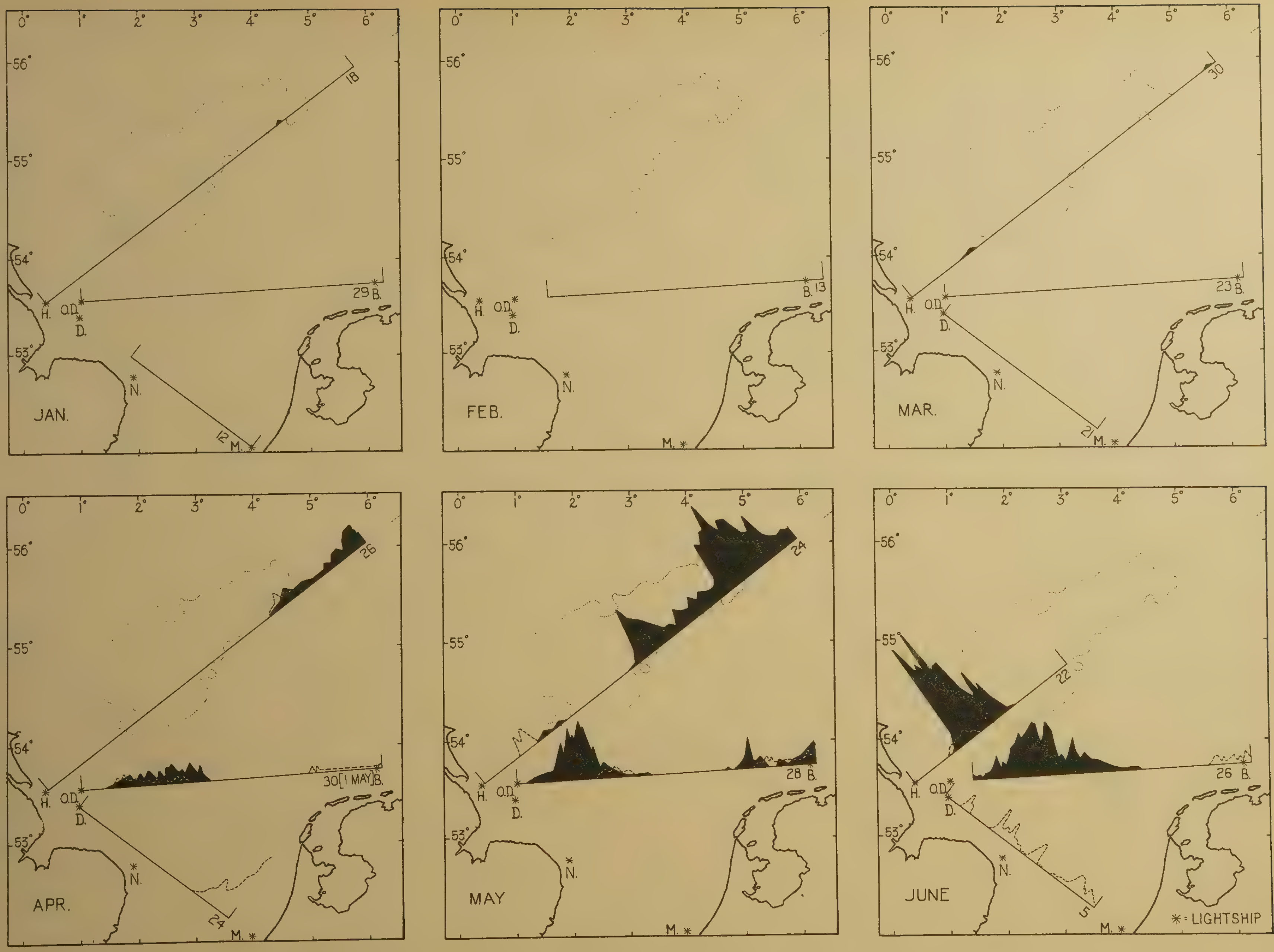
DINOFLAGELLATES (*blacked-in graph*) *and* **PHAEOCYSTIS** (*broken line*), 1934, *see explanation on Plate XLV.*

PLATE L


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
JULY
H.
O.D.
D.
N.
M.
B.
27
21
31 [1 AUG]
AUG.
25
18
29
SEPT.
8
29
19
OCT.
13
6
2
7
11
NOV.
3
10
14
4
DEC.
1
✱ = LIGHTSHIP

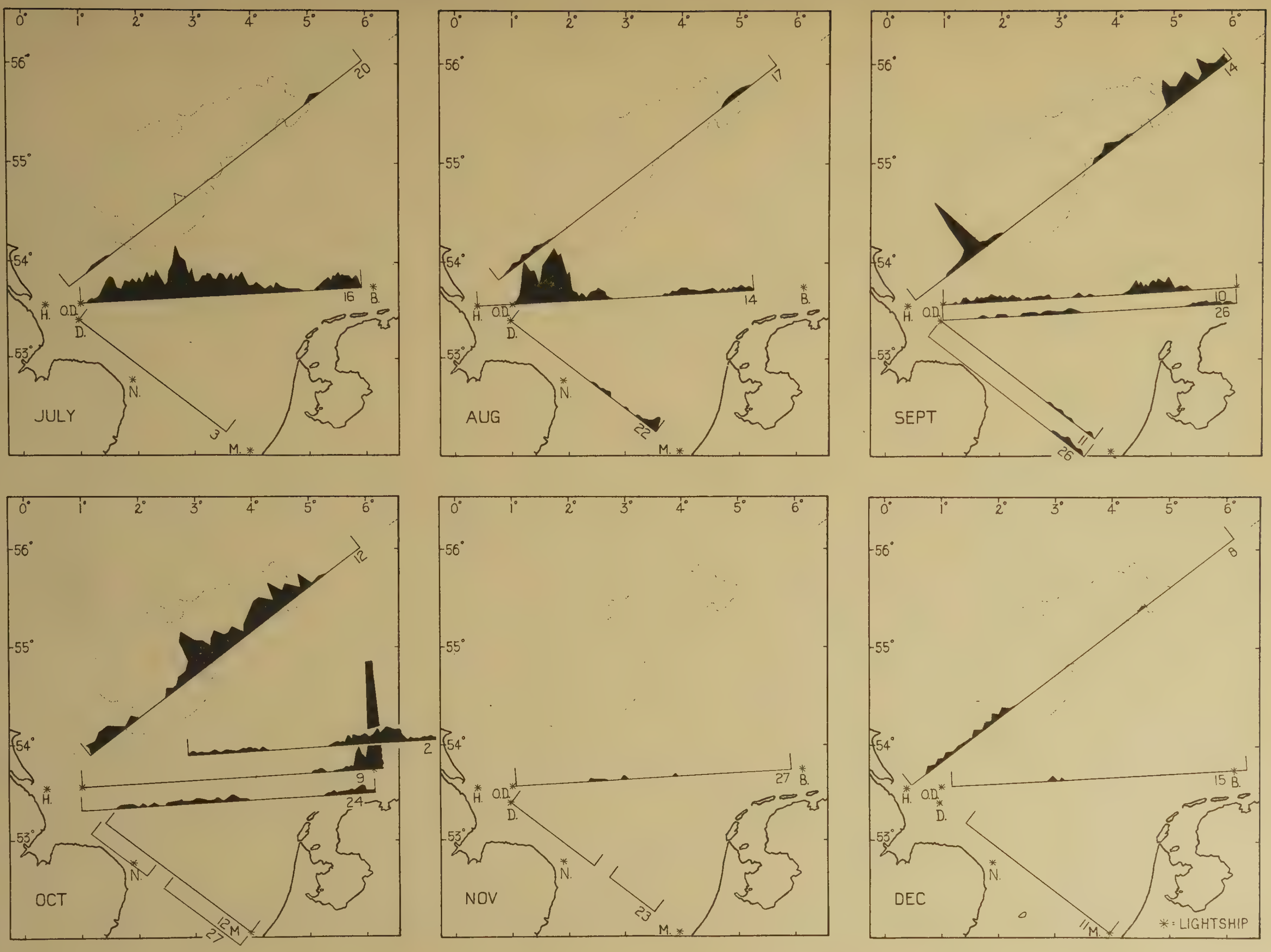
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1934, see explanation on Plate XLV.*

PLATE LI


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
JAN.
H.
O.D.
D.
N.
12 M.
29 B.
18
FEB.
M.
B. 13
MAR.
21 M.
23 B.
30
APR.
24
30 [1 MAY] B.
26
MAY
28 B.
24
JUNE
5
26 B.
22
✳ = LIGHTSHIP

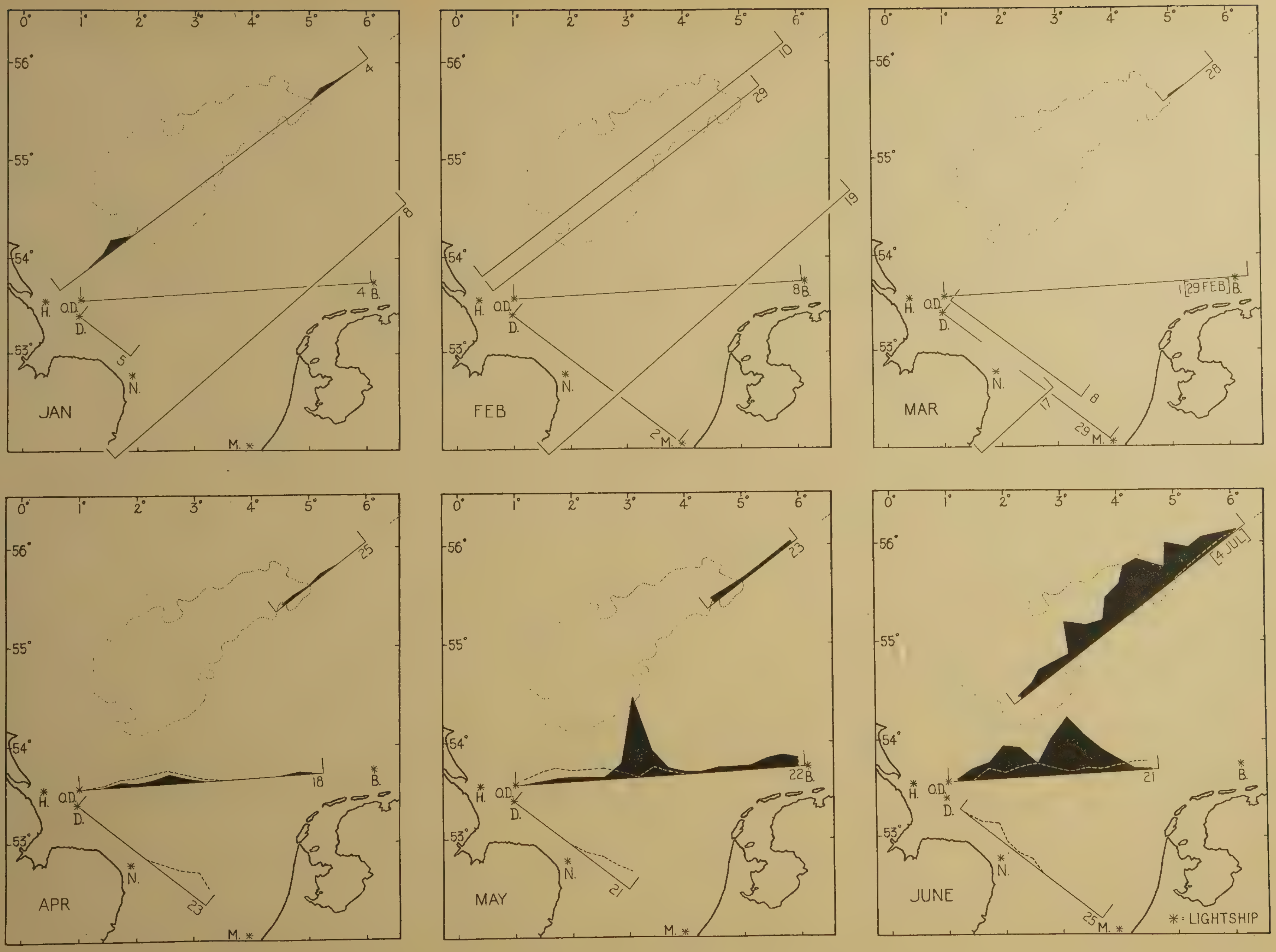
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1935, see explanation on Plate XLV.*

PLATE LII


JULY
AUG
SEPT
OCT
NOV
DEC
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
20
16
3
17
14
22
14
10
26
11
26
12
2
9
24
12M
27
27
23
8
15 B.
11M.
✳ = LIGHTSHIP

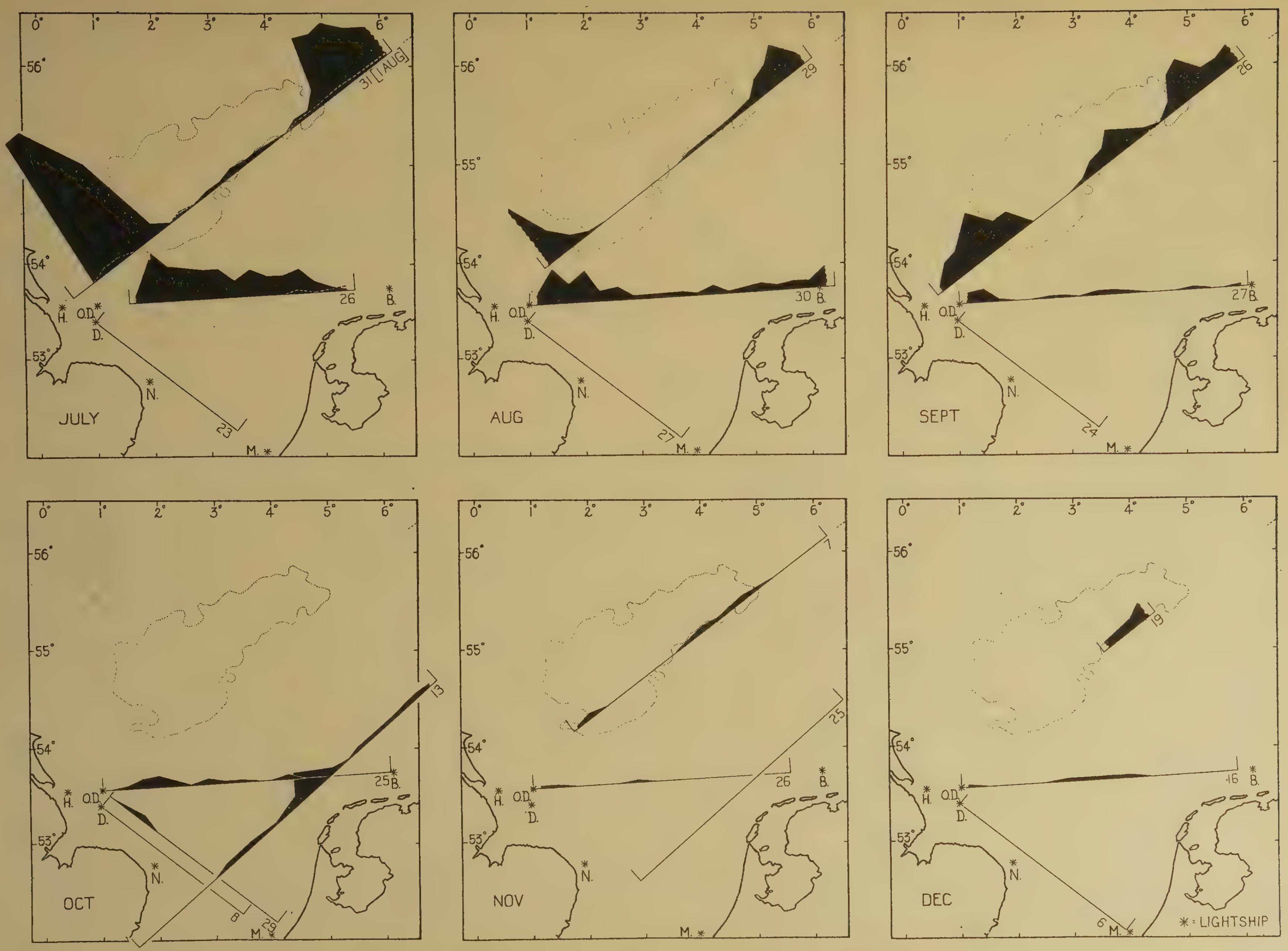
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1935, see explanation on Plate XLV.*

PLATE LIII


JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
4
5
8
4 B.
10
29
19
8B.
2 M.
28
1 [29 FEB] B.
8
17
29 M.
25
18
23
23
22 B.
21
[4 JUL]
21
25 M.
✳ = LIGHTSHIP

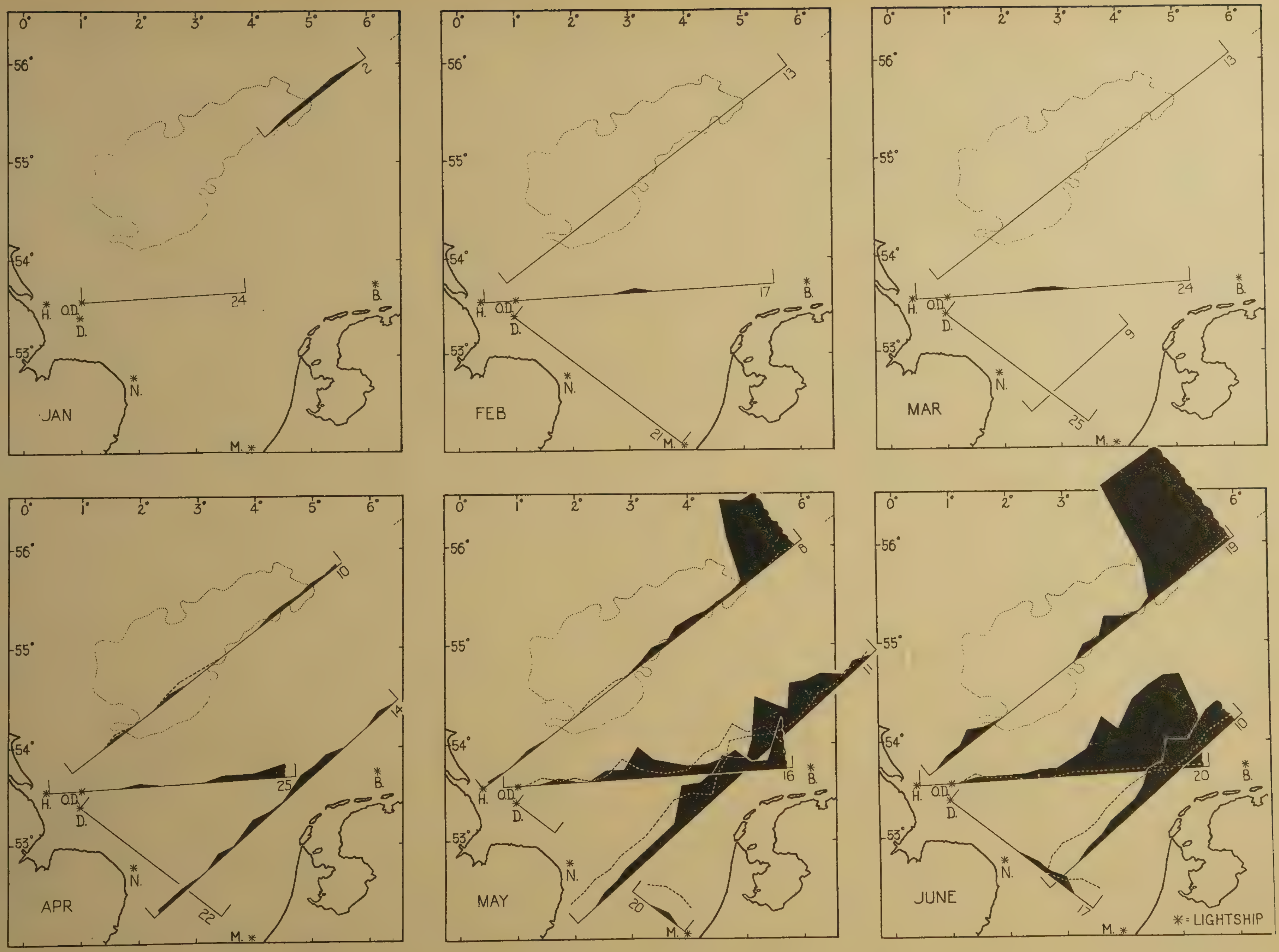
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1936, see explanation on Plate XLV.*

PLATE LIV


JULY
31 [1 AUG]
26
23
AUG
29
30
27
SEPT
26
27
24
OCT
13
25
8
29
NOV
25
26
DEC
19
16
6
H.
O.D.
D.
N.
M.
B.
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
* = LIGHTSHIP

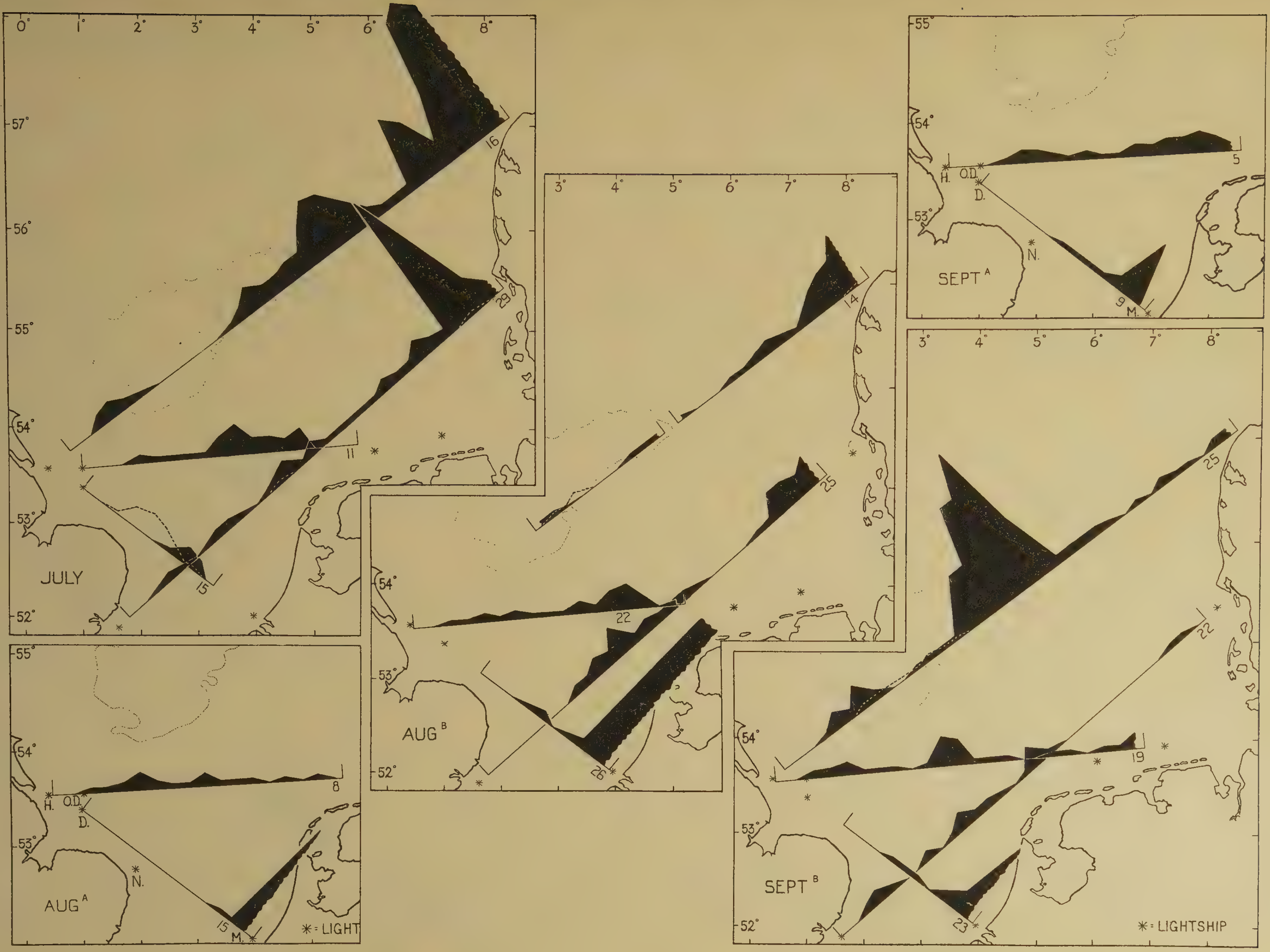
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1936, see explanation on Plate XLV.*

PLATE LV


JAN
FEB
MAR
APR
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
2
24
13
17
21
9
25
10
14
22
8
11
16
20
19
17
✳ = LIGHTSHIP

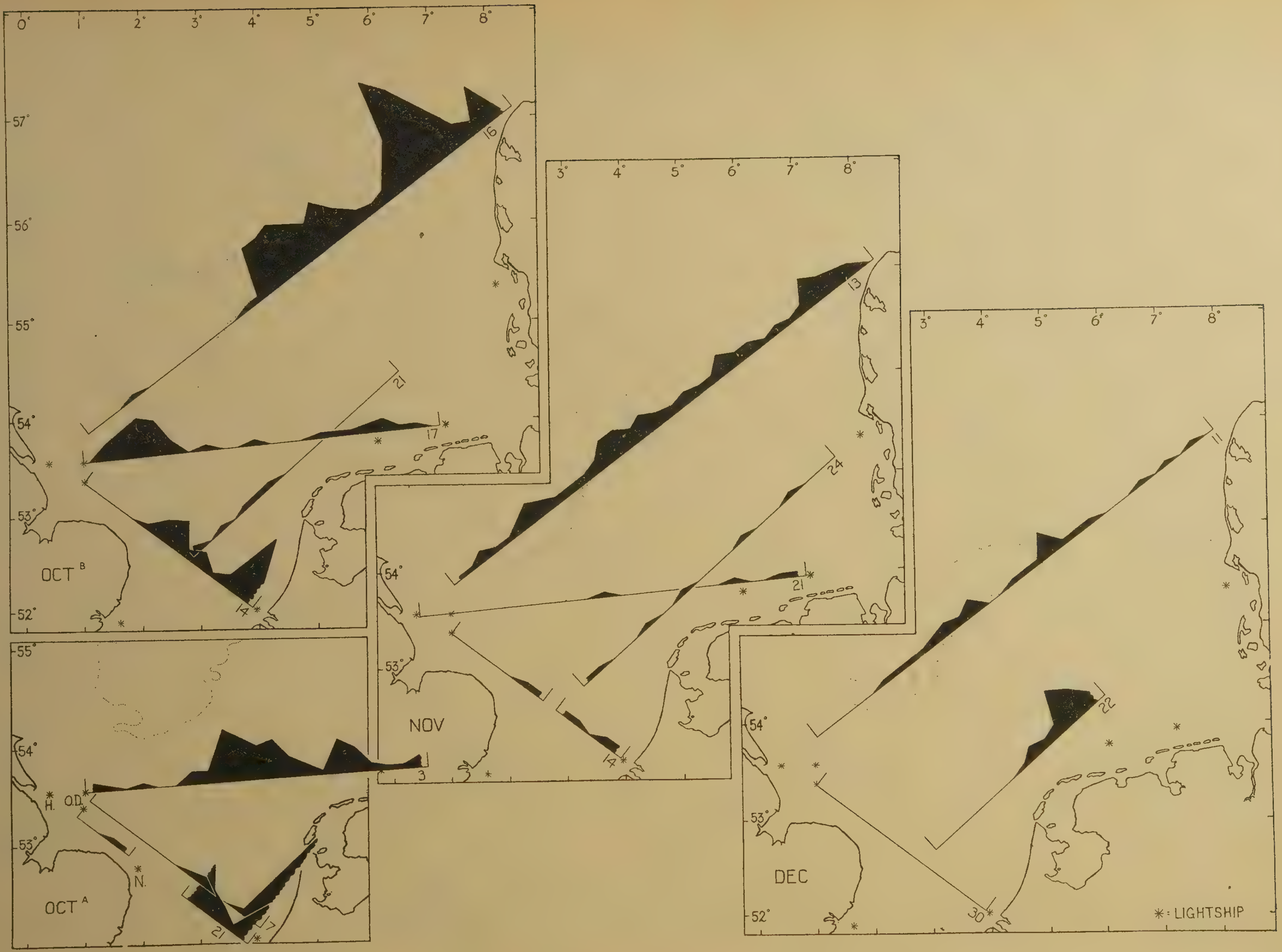
DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1937, see explanation on Plate XLV.*

PLATE LVI


JULY
AUG A
AUG B
SEPT A
SEPT B
H.
O.D.
D.
N.
M.
16
29
11
15
14
25
22
26
8
5
9
19
23
✳ = LIGHT
✳ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
8°
52°
53°
54°
55°
56°
57°

DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1937, and continued on Plate LVII, see explanation on Plate XLV.*

PLATE LVII


OCT B
OCT A
NOV
DEC
*: LIGHTSHIP
H.
O.D.
N.
0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
21
17
14
13
24
3
11
22
30

DINOFLAGELLATES *(blacked-in graph) and* **PHAEOCYSTIS** *(broken line), 1937 continued, see explanation on Plate XLV.*

Explanation of
PLATES LVIII–LXIV

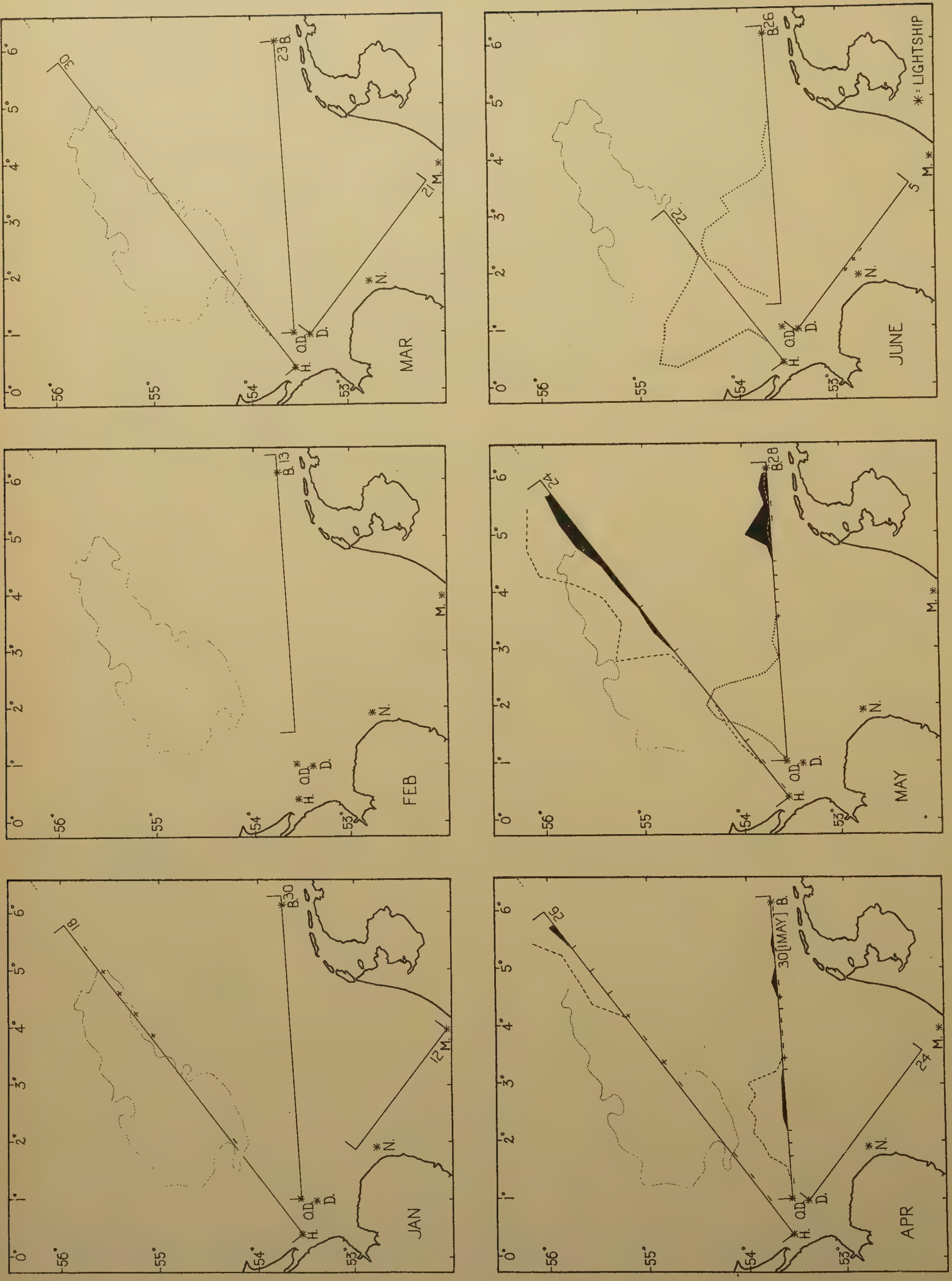
showing the distribution of ***CERATIUM FURCA*** and
C. FUSUS in the southern North Sea month by month
during the years 1935-1937.

When more than one record have been obtained on one line in any month they have been included where possible; others omitted will be found on Plates XVI—XVIII.

CERATIUM FURCA is shown as broken line and *C. FUSUS as* blacked-in graphs. On a few occasions in 1935, when no detailed analysis was made, the corresponding graphs for TOTAL DINOFLAGELLATES have been provided in dotted line.

Other details of maps as explained on Plate XXII.

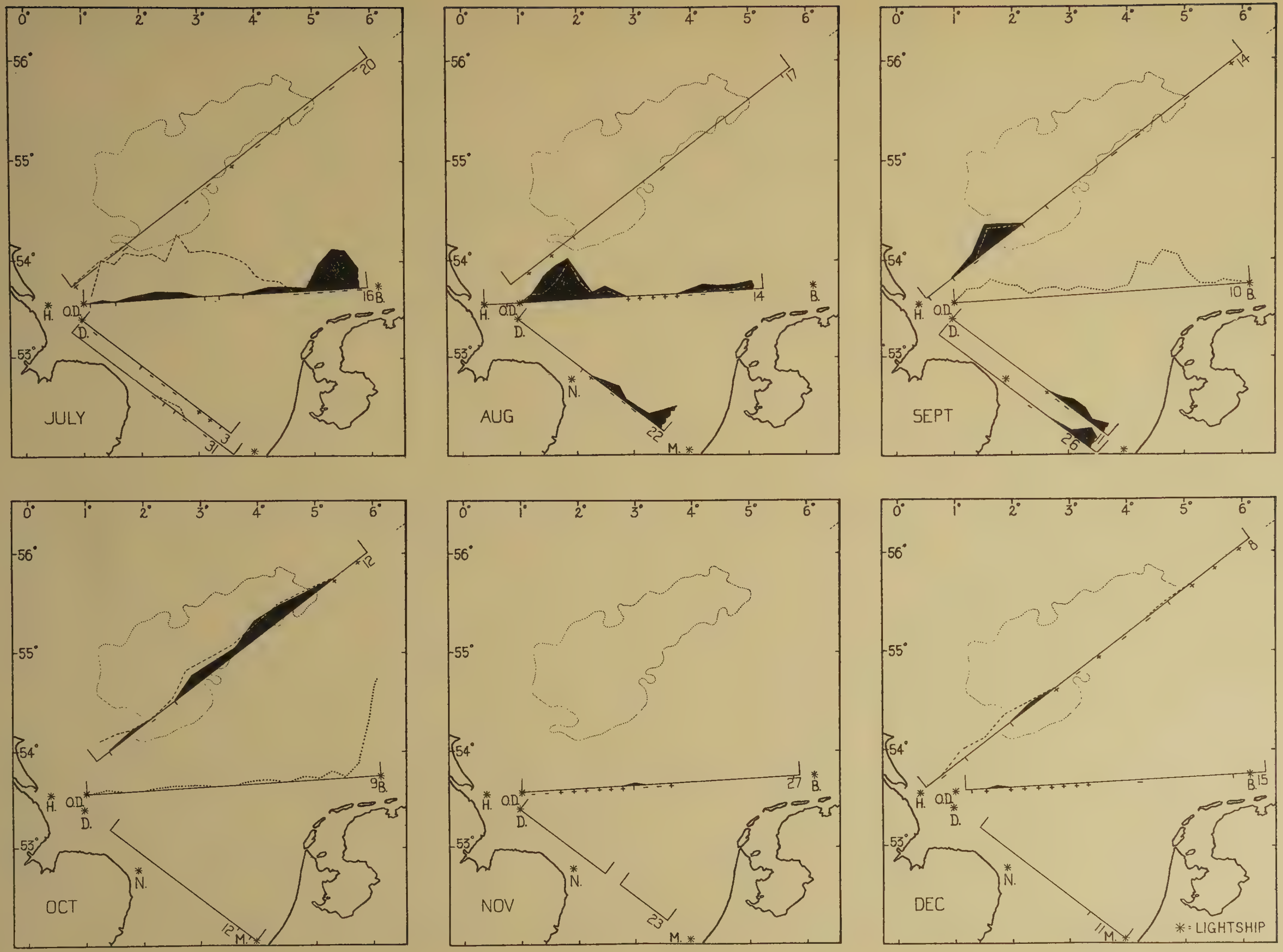
PLATE LVIII



JAN
FEB
MAR
APR
MAY
JUNE
H.
O.D.
D.
B.
M.
N.
18
30
12
13
30
23
21
26
30 [1 MAY]
24
24
28
22
26
5
✱ = LIGHTSHIP
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°

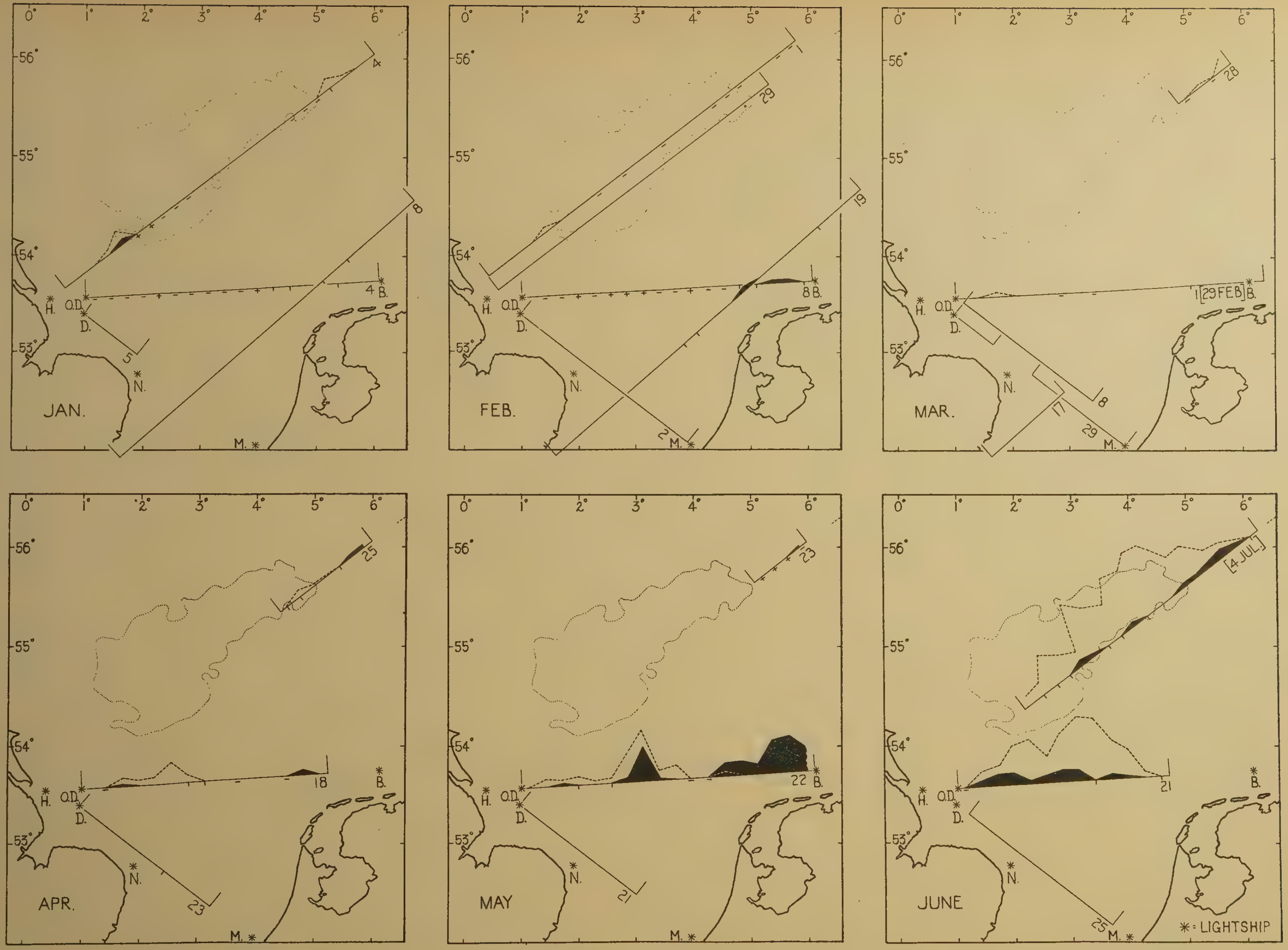
CERATIUM FURCA (*broken line*) *and* **C. FUSUS** (*blacked-in graph*), *1935, see explanation on previous page.*

PLATE LIX


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
JULY
20
16
31
3
AUG
17
14
22
SEPT
14
10
26
11
OCT
12
9
12
NOV
27
23
DEC
8
15
11
✱ = LIGHTSHIP

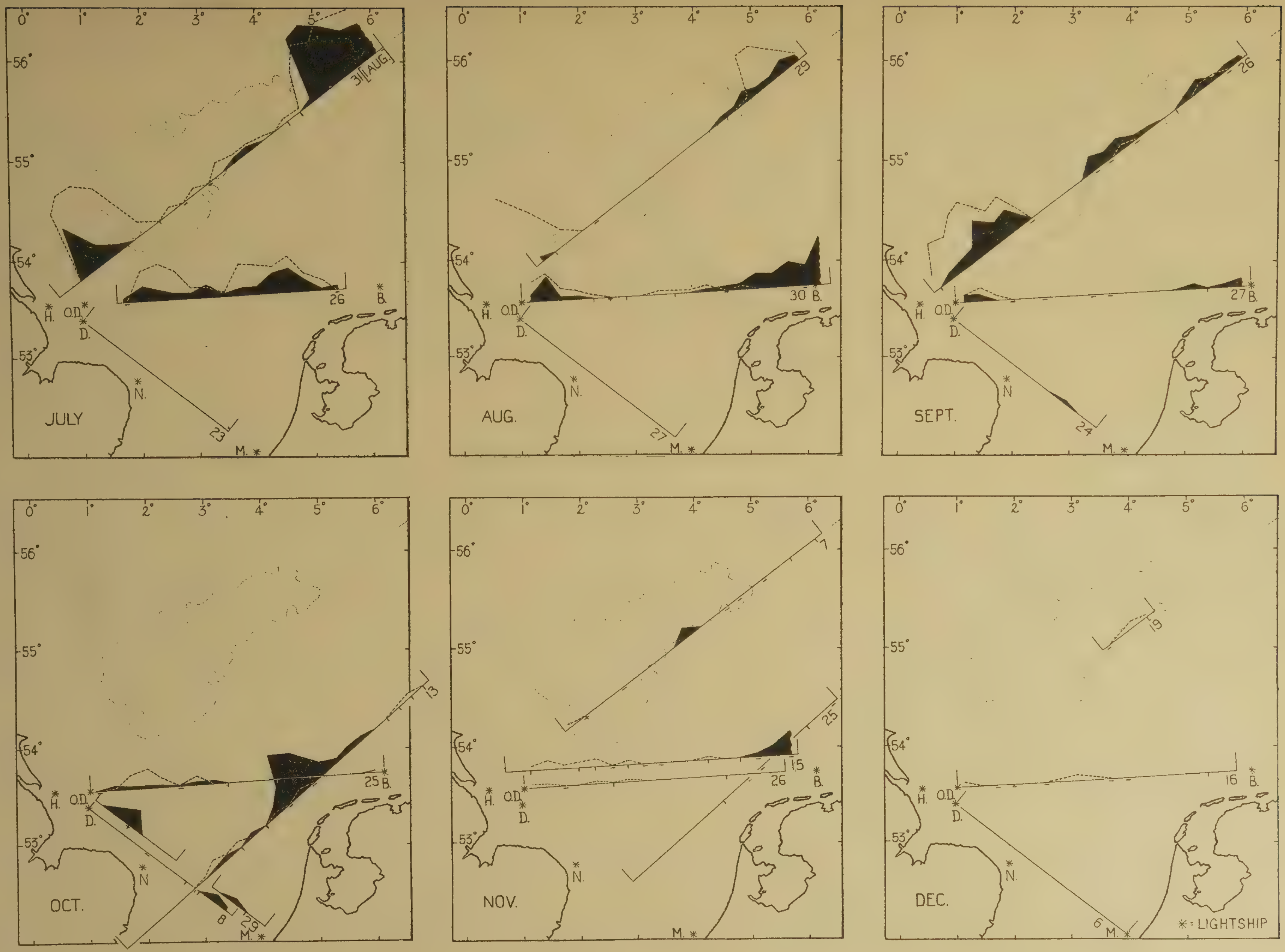
CERATIUM FURCA *(broken line) and* ***C. FUSUS*** *(blacked-in graph),* 1935, *see explanation preceding Plate LVIII.*

PLATE LX


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
4
8
5
29
19
2
1
8
28
[29 FEB]
17
29
25
18
23
22
21
[4 JUL.]
25
✳ = LIGHTSHIP

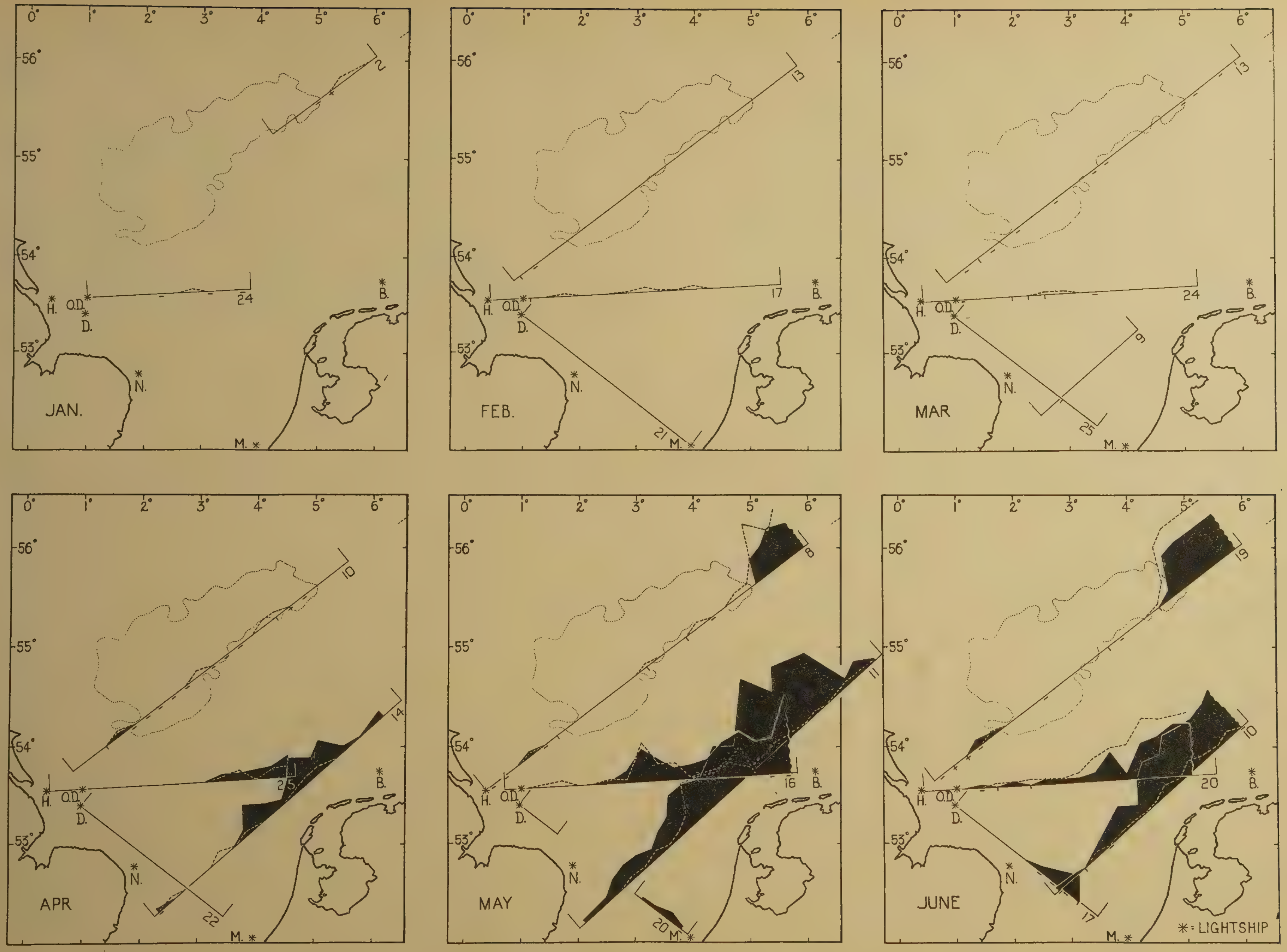
CERATIUM FURCA *(broken line) and* **C. FUSUS** *(blacked-in graph), 1936, see explanation preceding Plate LVIII.*

PLATE LXI


JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
31 AUG.
26
23
29
30
27
24
13
25
8
7
15
19
16
6
✳ = LIGHTSHIP

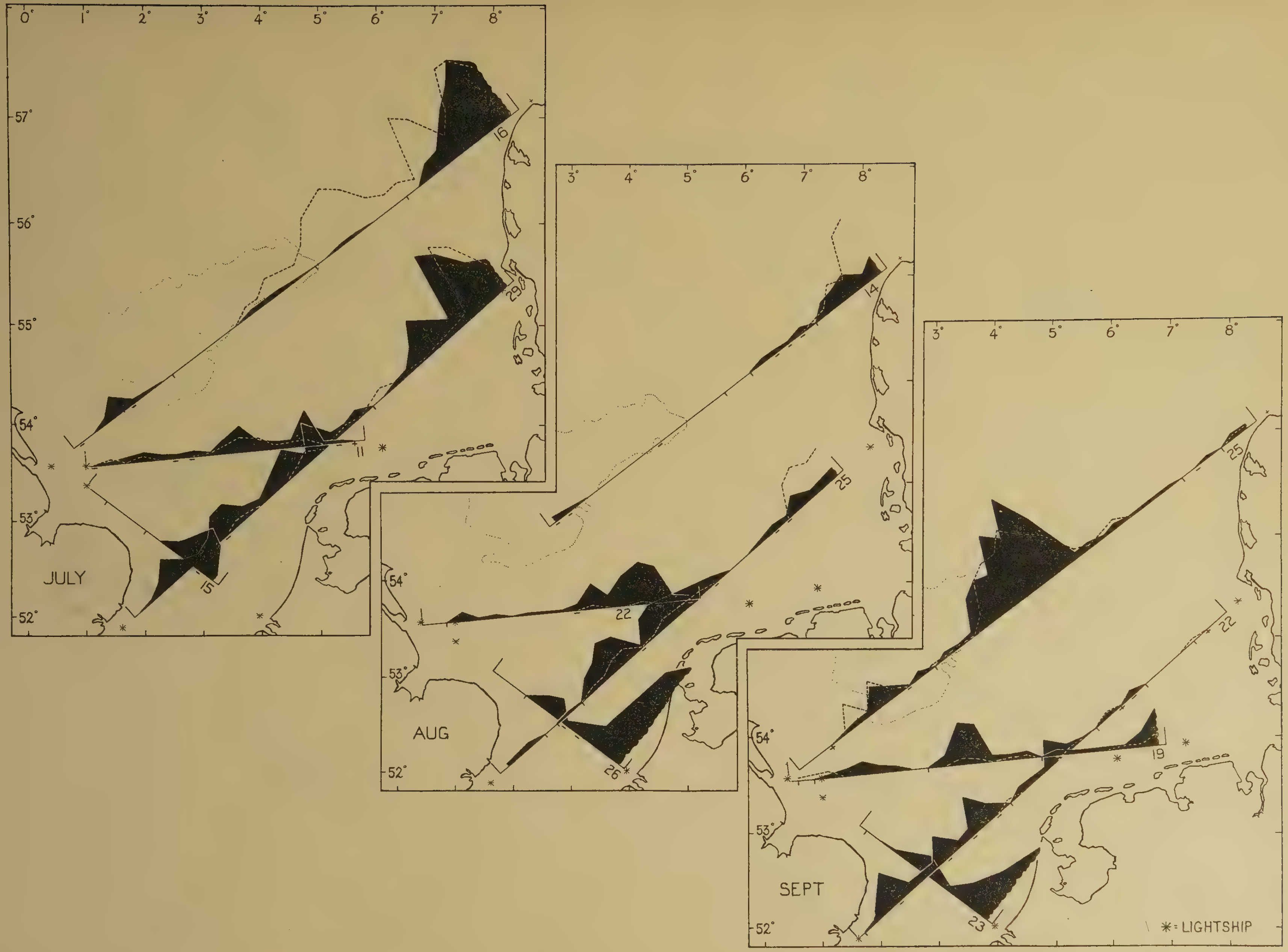
CERATIUM FURCA (broken line) and **C. FUSUS** (blacked-in graph), 1936, see explanation preceding Plate LVIII.

PLATE LXII


JAN.
FEB.
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
2
24
13
17
21
9
25
10
14
25
22
8
11
16
20
19
10
20
17
✱ = LIGHTSHIP

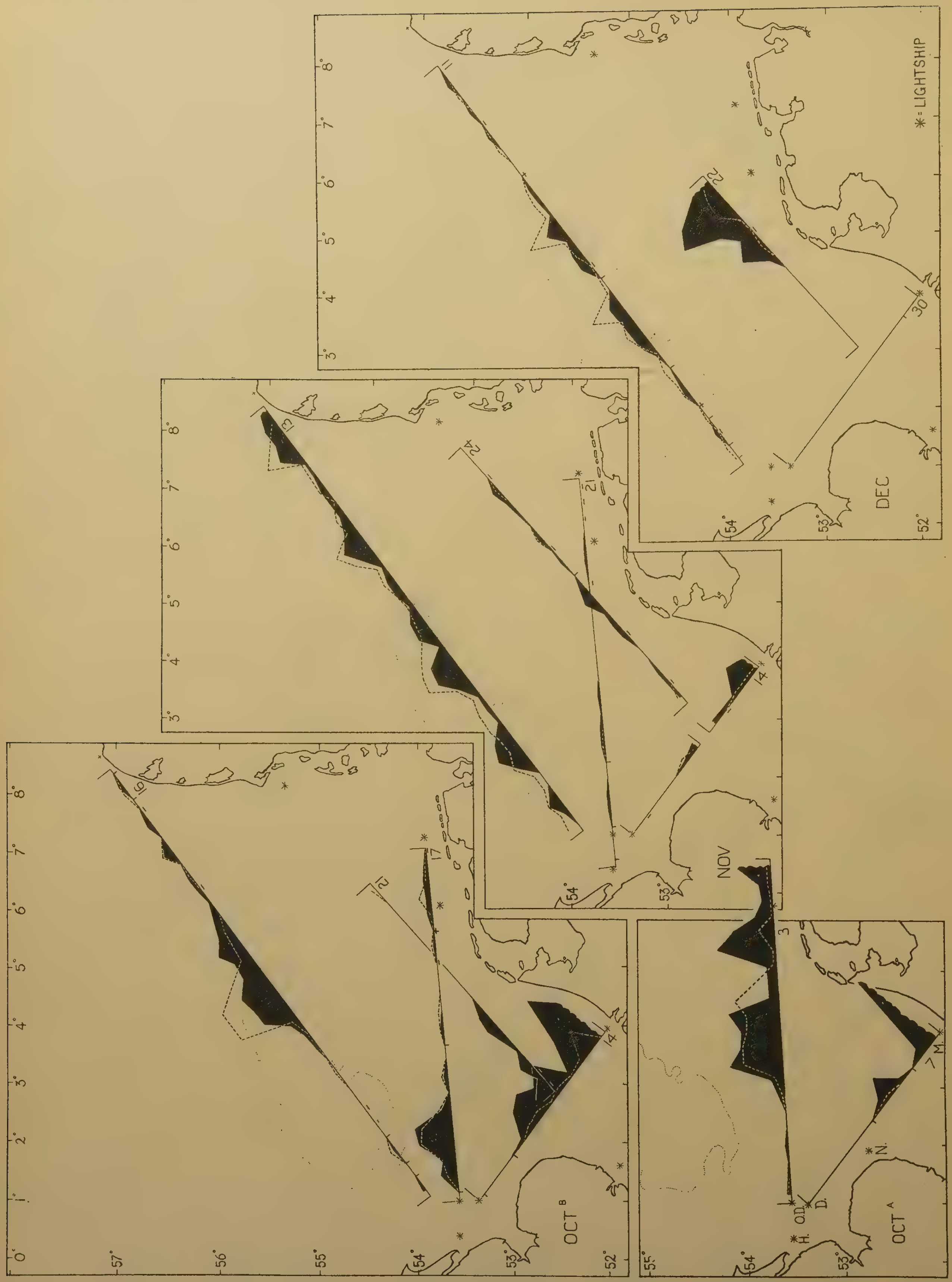
CERATIUM FURCA *(broken line) and* **C. FUSUS** *(blacked-in graph), 1937, see explanation preceding Plate LVIII.*

PLATE LXIII


JULY
AUG
SEPT
0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
29
11
15
14
25
22
26
19
23
✻ = LIGHTSHIP

CERATIUM FURCA (broken line) and **C. FUSUS** (blacked-in graph), 1937, and continued on Plate LXIV, see explanation preceding Plate LVIII.

PLATE LXIV


OCT B
OCT A
NOV
DEC
✱ = LIGHTSHIP
H.
O.D.
D.
N.
M.
0°
1°
2°
3°
4°
5°
6°
7°
8°
52°
53°
54°
55°
56°
57°
11
13
14
16
17
21
22
24
30
3

CERATIUM FURCA *(broken line) and* **C. FUSUS** *(blacked-in graph), 1937 continued, see explanation preceding Plate LVIII.*

[*Hull Bulletins of Marine Ecology, Vol. I, No. 4, pp. 171–238, Plates LXV–CXXV, September, 1941.*]

ECOLOGICAL INVESTIGATIONS WITH THE CONTINUOUS PLANKTON RECORDER:

THE COPEPODA OF THE SOUTHERN NORTH SEA, 1932–37

BY

K. M. RAE, B.Sc.,
Leverhulme Fellow, University College, Hull,

AND

J. H. FRASER, M.Sc.,
Leverhulme Fellow, University College, Hull, 1932–1935

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THE DISTRIBUTION OF THE "TOTAL COPEPODA" 187

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[1] Mr. Fraser was Leverhulme Fellow from 1932 until 1935, when he resigned to take up his present position with the Fishery Division, Scottish Home Department. He made the general analysis of a considerable proportion of the Recorder rolls taken during these first three years of the survey. The estimations of the constituent species which form the subject matter of the second part of this report were made by Mr. Rae.

PART I.—GENERAL CONSIDERATIONS AND THE DISTRIBUTION OF THE COPEPODA AS A WHOLE.

INTRODUCTION.

IN 1932 Professor A. C. Hardy instituted a long-term survey of the plankton of the southern North Sea, using the Department of Zoology and Oceanography at University College, Hull, as a centre. The scheme departed from the conventional oceanographic methods by adopting the Continuous Plankton Recorder as the means of collecting the material. This automatic sampling instrument and the general methods and aims of the survey are fully described in ‘ Bulletin ’ No. 1.

The purpose of this report is to present a study of the varying distribution and abundance of the Copepoda in the southern North Sea from the middle of 1932 to the end of 1937. Part I deals with the copepod population as a whole and Part II with the more important constituent species or groups of species. That there are considerable variations in the numbers of the Copepoda in the area from season to season and from year to year has long been known from many previous cruises and particularly from the quarterly observations made in the plankton investigations of the International Council for the Exploration of the Sea during the years 1902–1908. The present investigation, by repeating continuous lines of observation across the area, as far as possible once a month, for five and a half years, aims at providing answers to such as the following questions: Is the seasonal sequence of changes in the population of the area broadly the same year after year? How great are the ranges of fluctuation usually encountered ? Are phases of exceptionally high or low production usually only of short duration ? Do two or more species tend to fluctuate together ? Do some species tend to be more evenly spread throughout the area than others ? When we find a markedly uneven distribution in the area, does such a pattern of distribution tend to be repeated at the same season in subsequent years ?

It is intended that this Bulletin should be taken together with those dealing with the other zooplankton (Henderson and Marshall, *in the press*) and the phytoplankton (Lucas, 1940) to provide a picture of the changing plankton community as a whole. A discussion of the possible causes underlying the fluctuations found is reserved for a later paper when the results of all three reports will be considered in relation to the hydrological changes in these and adjacent waters.

With the co-operation of a number of steamship lines the Recorder was towed once a month when weather conditions and sailing schedules permitted on the following routes :

1. Between Hull and Rotterdam (East Dudgeon Light-vessel—Maas Light-vessel).
2. Between Hull and Bremerhaven (Outer Dowsing Light-vessel—Borkum Light-vessel).

3. Between Hull and Copenhagen (Humber Light-vessel—100 miles short of Hanstholm Light).
4. Between London and Esbjerg (Sunk Light-vessel—Graadyb Light-vessel).

The London-Esbjerg line was started experimentally in 1936, and did not run regularly until 1937. In the latter part of 1937 the Hull-Copenhagen line was extended as far as the Hanstholm Light, an extra 103 miles, and the Hull-Bremerhaven line to the Norderney Light-vessel, about 60 miles east of Borkum Light-vessel.

A list of the sailing dates, the times of shooting and hauling of the machine, the lengths of tow, the prevailing weather conditions and other particulars are published in ' Bulletin ' No. 2.

It may be recalled that in the Continuous Plankton Recorder the plankton is caught upon a long strip of silk gauze which is slowly wound across the flow of water passing through the internal mechanism as the machine is towed along. This silk strip is marked off into 2-in. divisions, each of which samples the plankton for a distance which can be estimated for each record, and is referred to as the " graduated silk." Directly after passing across the water flow it is met by a second band, known as the " plain silk," and together, sandwiching the plankton between them, they are wound on to a spool in a tank containing formalin. When the machine is returned to the laboratory this storage spool or " roll " is removed and put in neutral formalin to await analysis.

In the earlier years of the Department when the Continuous Plankton Recorder was only just emerging from what may be described as an experimental phase, a considerable amount of time had to be spent in designing and trying out minor modifications to assure the relatively high standard of working efficiency which has been a feature of the machine during the greater part of the survey. In addition to this the detailed correlations between the samples taken by the Plankton Indicator and herring catches (Hardy, Henderson, Lucas and Fraser, 1936) occupied a further considerable proportion of the time available, and consequently it was not possible to undertake a detailed analysis of the recorder material for the first few years. A number of arbitrary categories, which could be readily distinguished on the silk, had to be adopted as a basis for identification, although it was realized that some of them were not sufficiently specific to be ideal for ecological considerations. At this time specific identification of the Copepoda on the silk was deemed impracticable, so all species were included in a single category.

The economic importance of the Copepoda has been pointed out by a large number of workers. There is no space available here to review the literature, but we may remind the reader of one or two of the significant points in some of the more recent papers on the subject. Lebour (1921), referring to the herring, sprat and pilchard, writes, " They all eat much the same sort of pelagic food, copepods being the commonest in all after about 12 mm.," and states that the sprat still eats mostly copepods and larval molluscs after metamorphosis. Hardy (1924) lays particular stress on the importance of the smaller species, especially *Pseudocalanus* *elongatus*, in the diet of the developing herring, and shows what a large proportion of the food of the adult may be made up by the group. Savage (1931 and 1937) and Cambell (1934) give further evidence of this, while Hardy, Henderson, Lucas and Fraser (1936) show that the relative abundance of *Calanus finmarchicus* may be a good indication of the presence of herring, and give practical examples of how this inter-relationship may be used to assist the fishery. Ogilvie (1938) finds that the post-larval haddock in the Scottish area is also to a very large extent dependent on the copepod community as a source of food, almost 90% of the stomach contents of those from 3·5 to 17 mm. in length being comprised of ova, nauplii, copepodids and adults. Hart and Wailes (1932) correlate the oil content of the pilchards caught off the coast of British Columbia with the quantity of copepods in their diet; while Clarke (1934), in assessing the role of the copepods in the economy of the sea, lists mackerel, herring, pilchard, alewife, shad, blueback and pollack as fish which are known to feed chiefly on the group.

In view of these points it seemed possible that a long-term survey of the fluctuations in the combined copepod population might throw some light on the variations in the commercial fisheries, and for this reason we include in this report an account of the distribution of the Copepoda as a whole, although it must be realized that this category is comprised of many species with well known and pronounced ecological differences.

Method of Analysis.

The procedure followed in examining the Recorder rolls is described in detail elsewhere (‘Bulletins’ Nos. 1 and 3). From the beginning of the survey until the beginning of 1936 the copepods were estimated in the following manner.

The graduated and plain silks were separated on a specially designed stage and each 2-in. division of silk was crossed by one traverse of a travelling microscope, using a $\frac{2}{3}$ in. objective and a × 6 ocular. The traverse was made near the centre of the division on the graduated silk and at a corresponding position on the plain. At times almost all the plankton was found to have remained on the graduated or filtering silk, but at others, especially when *Phaeocystis* was present, considerable quantities stuck to the plain or covering silk. In all cases those copepods seen in the traverse on the plain silk were added to those counted on the graduated. It was found that the area included in the field of these two traverses was a close approximation to 1/20 of the area of the 2-in. division and its corresponding 2 in. of covering silk, so the number of copepods per division was estimated by multiplying the number seen in the two cross traverses by 20.

As explained above, each division of the graduated silk had collected for a certain distance, which varied between 1·5 and 2·5 miles per division from record to record, but could be fairly accurately worked out in any one record. In order to make the data comparable for all records the numbers of copepods estimated on each division were converted to the numbers caught per mile of tow by dividing by this ratio.

A copepod was only included in the count when the proximal ends of its first antennae were in the field. This point was found to be a satisfactory criterion, as it is easily recognizable even in the most damaged specimens, and at the same time is sufficiently localized to overcome the difficulty of the size discrepancy in the group.

In addition to the total copepod estimate made with the microscope, a subsidiary examination was made with a low-powered lens or the naked eye. The purpose of this was to get as reliable value as possible for the larger species, which rarely occurred in numbers sufficiently high to be adequately estimated by the subsampling method. During this examination the late copepodids and adults of Calanus and Labidocera were counted.[1]

The plankton was then scraped from each division and its corresponding area on the plain silk with a razor-blade and placed, section by section, in separate tubes of formalin for the subsequent analysis of constituent species, when time became available.

After 1935 it was realized that data was accumulating faster than it could be analysed, and it became essential to reduce the scale of working. In order to do this, it was decided that after a roll had been analysed for phytoplankton, it should be cut up into lengths each representing 10 miles of tow. These lengths usually consisted of six or seven 2-in. divisions, and instead of taking a cross traverse on each division, only three were made, evenly spaced along the 10-mile length and, as before, three similarly spaced traverses were made on the plain silk. The copepods seen in these six traverses were again converted to an estimate of the number of copepods per mile of tow and were therefore directly comparable to the previous data.

Those records taken after May, 1937, were subjected to another modification. To economize in the quantity of silk used, the rate of winding through the Recorder was decreased by altering the pitch of the driving propeller blades, until a 2-inch division represented about 5 miles instead of about 2 miles. The 10-mile block now consisted of approximately two divisions of silk, and only one traverse was taken on the graduated part and one on the plain.[2] To prevent clogging of the silk as a result of the increased period of filtering, it was thought wise to replace the $\frac{3}{4}$-in. sq. aperture in the nose of the Recorder with one $\frac{1}{2}$-in. sq. This new aperture was calculated to allow only $\frac{4}{9}$ as much water to pass through the recorder as before, and so to compensate for the fact that on account of the reduced winding speed each division of silk was filtering approximately $2\frac{1}{2}$ times as long as previously. Such a double change, although keeping quantities of plankton deposited on the silk roughly constant, did of course reduce the numbers caught per mile of tow by 2¼ times. This necessitated either raising the 1937 or reducing the 1932–36 estimates by this figure to make them comparable. The latter course was adopted, so that the figures presented here would be consistent with those in subsequent reports. All the scales appended to the diagrams indicate the numbers that would have been estimated had the ½-in. sq. aperture been used from the beginning of the survey. These successive modifications of the Recorder have been described and discussed more fully by Professor Hardy in 'Bulletin' No. 1.

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[1] This was only adopted as part of the regular routine in 1934 after the Indicator work had shown the importance of the Calanus-herring correlations (Hardy, Henderson, Lucas and Fraser, 1936).

[2] These traverses were "staggered," *i.e.* taken in steps diagonally across the block.

Arrangement of the Data.

Graphs of the varying abundance of the copepoda along each record have been prepared. The base line represents the length of tow in miles and the vertical scale the estimated number of copepods per mile. In the bulk of the records, all those earlier than 1936, an estimate is plotted for every section, *i.e.* at intervals of 1½ to 2½ miles, depending on the calculated mile-division ratio in each particular case. From the beginning of 1936 onwards only one estimate is plotted every 10 miles, but it should be remembered that this figure is derived from the analysis of all the plankton collected in those 10 miles and not from a single section or limited part of the 10 miles.

These graphs are arranged in two ways.

Firstly, each route is considered separately so that fluctuations along its length may be considered over the whole 5½-year period and a comparison between years can be readily made. On Plates LXV–LXX the Rotterdam, Bremen and Copenhagen lines, and on Plate XCII the Esbjerg line, are taken in turn and for each the arrangement is the same. Down the side of each figure there is a time scale divided into the months of the year, and each record is placed against its appropriate date, so that the space between the base lines is proportionate to the time between the records. Each column of graphs represents one complete year from January to December, and the years are placed side by side.

Secondly, the same graphs are arranged together month by month on a series of small maps, with the base line of each in its correct geographical position. This enables one to see the distribution over the whole area at any one time. It must be remembered, however, that these maps are generalized impressions rather than instantaneous pictures of the distribution, because the records on any single map may cover a period as long as three weeks. This was inevitable on account of sailing schedules, bad weather and the limited number of machines available. The date of each record is placed under its right-hand end.

Limitations of the Method.

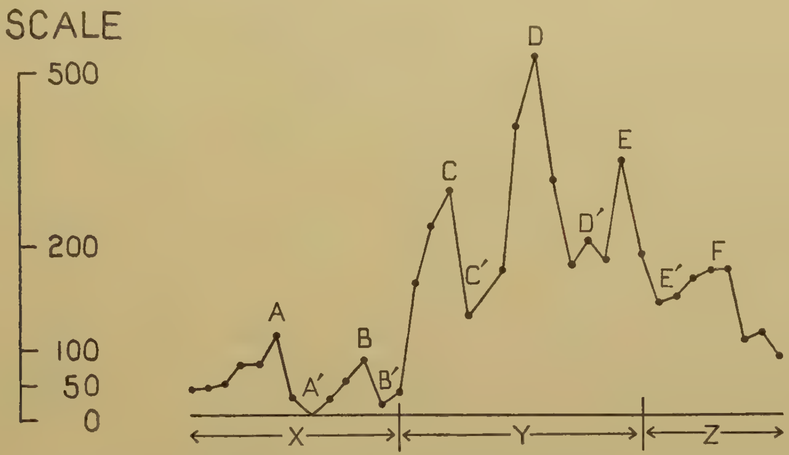
The advantages and deficiences of the Recorder method have been adequately discussed by Hardy ('Bulletin' No. 1) and Lucas ('Bulletin' No. 3). It is only necessary to mention here two of the limitations which affect more particularly the Copepoda. The first is the relatively poor catching power of the Recorder or the smallness of the sample at any one point of observation when compared with the more usual tow-net haul. This, of course, is inevitable if the machine is to be small enough to be easily handled, but at the same time is to take hundreds of samples without being hauled and reloaded; the ease and low cost with which vast numbers of samples can be taken is undoubtedly the outstanding feature of the Recorder. However, when the aperture has been reduced to prevent clogging on the length of silk that can be used in the mechanism, we find that the numbers of copepods caught per mile are low. The highest numbers estimated are of the order of 3000 individuals per mile when the $\frac{3}{4}$-in. sq. nosepiece is fitted to the machine or 1500 with the $\frac{1}{2}$-in. sq. nosepiece, but if all the results are considered it will be found that any figure over 1000 per mile is exceptional and the majority are of the order of 100 or less.

When such small samples are being used one must bear in mind the possibility of considerable variation from mile to mile due to the random sampling of the machine in the sea. Two samples may differ for two distinct reasons. In the first place they may have been taken from populations that are essentially different and so reveal the type of change sought in ecological study. Or secondly, they may have been taken from the same or a similar population, but nevertheless show a non-significant difference due to their random selection.

Superimposed on this possible error there is the experimental error entailed in the laboratory estimation of the number of individuals caught. As explained above, the method of estimation consisted of counting the number of individuals on a fraction of the silk, usually about one-twentieth, and multiplying the result by a suitable factor. Any such sub-sampling method introduces a random error, which at times may make the estimated total far from the actual total caught. Such discrepancies should not be frequent if the subsample is as large a fraction as one-twentieth, but subsequent comparison of the totals estimated on the silk and the check counts made of the scrapings showed that they did occur (see p. 199).

The smallness of the individual samples is a more serious matter in the consideration of the copepoda than the phytoplankton, as the range between the densest concentrations found and absence is so very much shorter. If the phytoplankton catches of the Recorder were analysed to the nearest 5000 individuals there would still be a clear distinction between the periods of abundance and scarcity, whereas a far less drastic procedure would tend to obscure all the seasonal variations of the Copepoda.

In view of these two sources of random error, the one in the sea and the other in the laboratory, both of which may on occasions combine to give a false impression of the actual concentration of the organism, it is clearly dangerous to put too much reliance on any single observation unless it is confirmed by others near it. It is impossible with the figures available to make any statistical estimation of the extent of these errors combined, because at no time has it been possible to take a large number of Recorder samples from a confined area to give a measure of the catching error, but some idea of their effect on the results may be derived from a consideration of the distribution graphs. It will be seen that these show a number of well-marked changes in concentration both in space and time, which are too large to be accounted for by any chance distribution, and further are shown by a number of successive but independent estimations. These are the major ecological variations that the survey was designed to reveal. Superimposed on these gross changes, there are, however, minor fluctuations which give the graph a wavy appearance. These may, of course, well be due to genuine minor patches or swarms only a mile or two in breadth, but it appears possible that they are artefacts produced by the errors entailed in the two random selections. Text-fig. 1 has been drawn to illustrate this point. The first forty divisions of record B. 3 have been replotted with a wider interval between each observation, so that each estimation is quite distinct from those on either side of it. Each division on this record represented 1·7 miles, so that each point plotted was this distance from its neighbour in the sea, but it should be borne in mind the number of copepods plotted on the vertical scale is an estimation of the number present in the 1·7 miles sampled and not the number at that particular isolated point.



TEXT-FIG. 1.—A graph of the estimated numbers of the " total Copepoda " on a part of a Bremen line record. For further explanation see text.

In this figure it can be seen that the distribution graph is made up of a number of peaks (A, B, C, D, E, F) alternating with troughs (A′, B′, C′ . . .), superimposed on the general trend. Whereas, for example, one can place little confidence in the peak " E " or the trough " C′ " which are shown by only one and two estimations respectively, there can be no doubt as to the validity of the general trend if it is expressed broadly: that is to say there were many more copepods in the water sampled by the tow Y than by X. This is quite clear from the fact that all the 13 estimations included in Y are higher than any of the 13 in X, and that their mean value is more than six times as high. This report deals with major differences shown by trends of this sort, which are far too pronounced to be greatly affected by the inaccuracies entailed in the sampling techniques. See also p. 203.

The second, and what at first sight must be thought the most serious limitation of the Recorder method, is that all samples are taken at a single depth—10 metres. This depth was selected as a compromise in the hope that it would give a fair picture of the distribution of both the phytoplankton and zooplankton. Lucas (' Bulletin ' No. 3) has shown that for the phytoplankton at least it is fairly satisfactory. Using figures published by Savage and Wimpenny (1936), he found a reasonable approximation to a straight line correlation between the numbers of cells taken in horizontal hauls at depths between 5 and 25 metres and the corresponding vertical hauls, and again between the numbers of cells in mid-water hauls and the mean of surface, mid-water and bottom hauls. However, as has already been pointed out by Hardy (' Bulletin ' No. 1), this limitation is likely to be much more serious in the case of the zooplankton, as so many of the organisms are known to make diurnal vertical migrations. Most of the work that has been done in the past on the vertical distribution of the Copepoda has been confined to the larger forms, *Calanus finmarchicus* especially being selected. Data have been produced by many authors for this species, but in view of the fact that it is omitted in the present report, and that it is relatively scarce in the area under consideration, we have decided to postpone any analysis of their figures until the later report dealing with the distribution of Calanus.

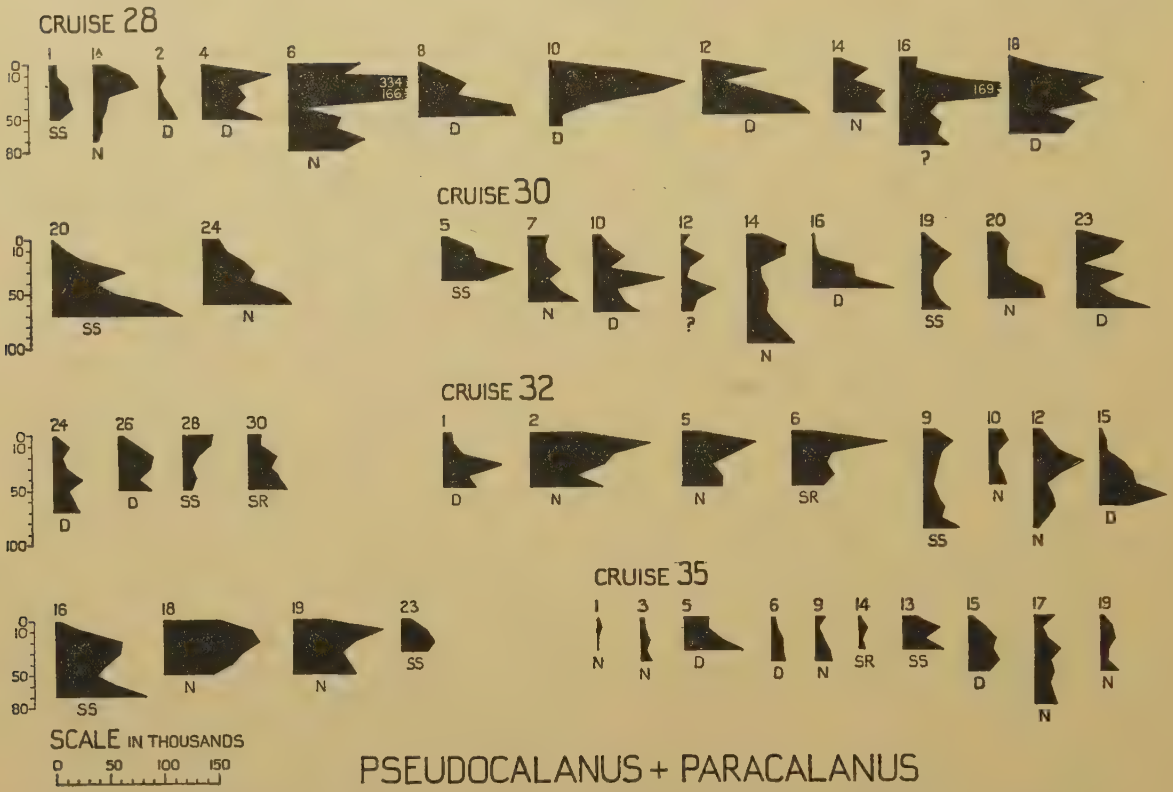
In order to form an estimate of the value of observations taken at a standard depth of 10 metres we must find out what proportion of the whole vertical population, for the commoner forms, we are likely to find at 10 metres at various times of day or at various seasons. Savage (1931) offers some very useful information on this subject. At a number of stations on four cruises in the summer and autumn of 1926, he took horizontal hauls at the surface and at 10-metre intervals to the bottom. His cruises covered the herring grounds and the bulk of his samples were taken from the Shields and Off-Flamborough areas, while a few of them came from further south off the East Anglian coast. They are then not far removed from a part of the area covered by the recorder survey, and although they are generally in slightly deeper water, they may be assumed to have sampled comparable populations. The vertical distributions of Pseudocalanus (+ Paracalanus) and *Temora longicornis* as found by Savage at these stations are shown diagrammatically in Text-figs. 2 and 3. There is in addition information for Centropages spp. from one cruise only. These diagrams bring out very well the variations there may be in the apparent density of the population between the surface and the bottom, and at the same time make it clear that the variations are of two types. Firstly there is the tendency for the bulk of the individuals to be nearer the surface or bottom, or at some mid-water level, and secondly, superimposed upon this, there are a number of irregularities in the distributions which are too pronounced to be accounted for by sampling or estimating errors. These may be described as examples of " vertical patchiness."

Under each diagram the letters D, N, SR or SS indicate whether the samples were taken in daylight or darkness, or within one hour of sunrise or sunset. It will be seen that generally, as might be expected, the majority of the copepods were deeper in the water during the hours of daylight, but that this was by no means invariably so. For example, the highest number of Temora taken was at 10 metres three-quarters of an hour before midday at Station 2 on Cruise 28, whereas on a number of occasions the larger numbers were found near the bottom after some hours of darkness, for example Pseudocalanus at Station 22 on Cruise 28, and at Station 20 on Cruise 30.

In order to test the probable effect of vertical migration or any other factor on the Recorder results, it is necessary to have some figures expressing the proportion of the copepods at 10 metres at each station. In the absence of more information we may average the horizontal catches from different depths to give an indication of the plankton there present, and so, by expressing the catch at 10 metres as a percentage of this average and comparing the percentages under various conditions, we can get an idea of the inaccuracies entailed in sampling at this depth only. To simplify the discussion, it is convenient to refer to this percentage as the " 10-metre value."

It is clear that over the period worked by Savage, a number of false impressions would have been obtained, had only his 10-metre hauls been considered. In the first place Pseudocalanus (+ Paracalanus) had a different vertical distribution from Temora over the whole period. The mean of the " 10-metre values " for all cruises was 98% for the former and only 54% for the latter, so that Temora would have appeared only about half as abundant as it should have done relative to the Pseudocalanus group. Secondly the vertical distribution of both forms varied from cruise to cruise. For Pseudocalanus (+Paracalanus) the average " 10-metre value " for Cruise 28, which was made towards the end of June, was 90%, for Cruise 30 in early August 83%, for Cruise 32 in early September 120%, and for Cruise 35 in mid-October 102%. Variations of this order need not be considered very disturbing, especially in view of the fact that there happened to be a higher proportion of day stations in the first two cruises than in the latter two. The figures for Temora on the other hand appear far less satisfactory, the mean " 10-metre values " for the four cruises being 57%, 13%, 70% and 85%. Differences of this kind might have a very serious effect on conclusions drawn from samples at 10 metres, as one would have had the impression that August was a particularly poor month for this species, when in fact it was quite as successful as September and October. It will be seen from Text-fig. 3 that at no time during Cruise 30 was there an appreciable proportion of Temora above 30 metres, with the exception of the very shallow Station 5, although it included three sets of night hauls and one near sunrise.

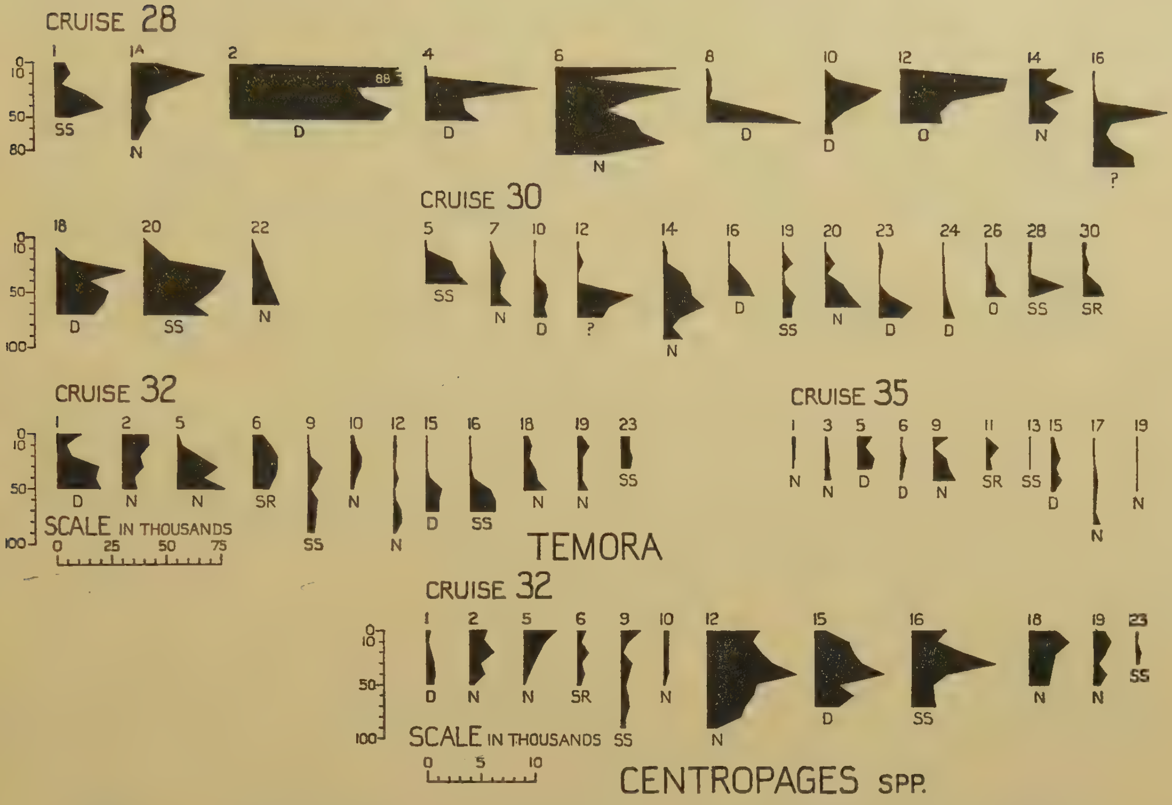
The effect of diurnal migration on the population at 10 metres can be summarized in the following way: The average " 10-metre value " for Pseudocalanus (+Paracalanus) at the 19 stations sampled between sunrise and sunset was 90·6%,



TEXT-FIG. 2.—Diagrams showing the vertical distribution of Pseudocalanus + Paracalanus at points in the North Sea during the summer and autumn of 1926 drawn from the data of Savage (1931). Above each diagram is the station number, and below it is an indication of the time of day at which the samples were taken: D for daylight, N for darkness, SS for within an hour before or after sunset, and similarly SR for sunrise. The vertical scales represent depth in metres, the horizontal scale the number of individuals taken in the tow-nettings.

while the 25 stations sampled between sunset and sunrise gave an average of 98·8%. This certainly appears to support Professor Hardy's contention in ' Bulletin ' No. 1 (p. 48) that in these shallower waters the effect of vertical migrations would prove relatively unimportant. Again, however, the results for Temora are less satisfactory, the average value for day being 40·8%, and for night 69%.

We may note in passing that the eight sets of hauls which were taken within one hour of sunset gave a relatively low average " 10-metre value " for both forms: 72·6% for Pseudocalanus (+Paracalanus) and 37·5% for Temora. These figures are surprisingly low in view of the suggestion made by Michael (1911) and supported by Russell (1927A) that organisms tend to concentrate most in the surface layers about the hours of sunrise and sunset. There were only three stations sampled within an hour of sunrise and these did give high average values at 10 metres: 145·7% and 111·3% for the two forms respectively. But clearly

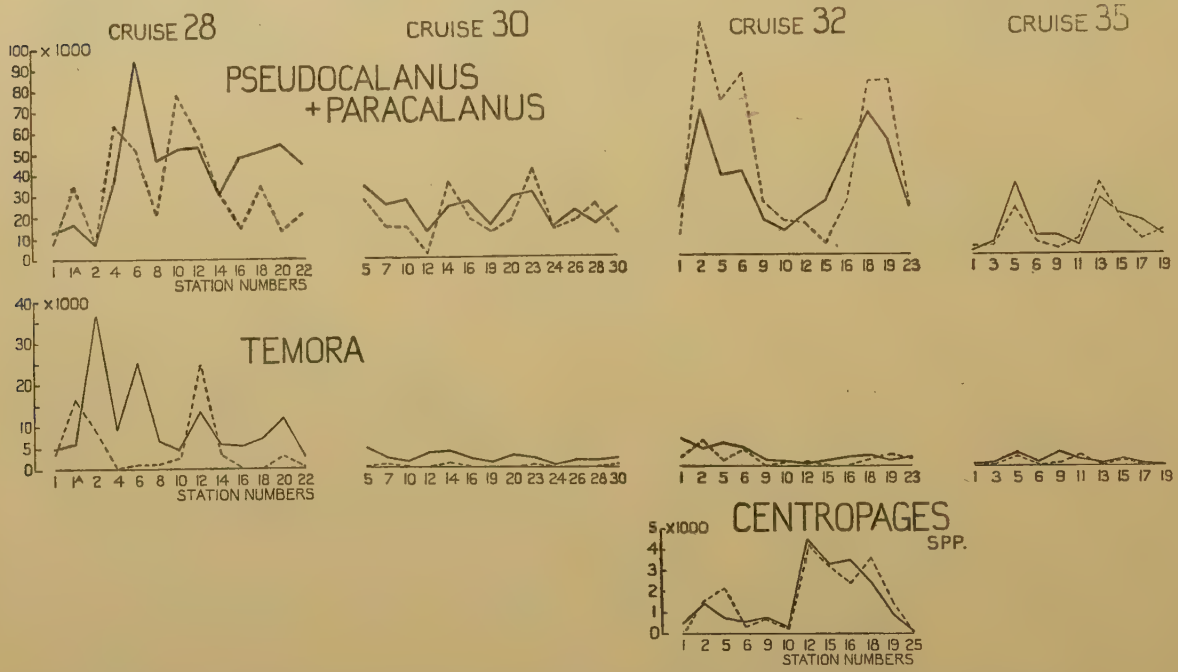


TEXT-FIG. 3.—Diagrams showing the vertical distribution of *Temora longicornis* and Centropages spp. at points in the North Sea during the summer and autumn of 1936 drawn from the data of Savage (1931) and arranged as explained under Text-fig. 2.

not much weight can be attached to figures derived from so small a number of observations available (either for sunset or sunrise).

We have also tried correlating the "10-metre values" with the depth of the stations, with the density of the population, and with the spatial arrangement of the stations. There was apparently no relationship in the first case. From the second, although there was no significant correlation, it was clear that a large proportion of the low "10-metre values" occurred when relatively few copepods were present at the station. This was especially so for Temora, as can be seen in Text-figs. 3 and 4. There was some suggestion that the third might have proved interesting had there been more stations spread over a larger area, as there was a tendency for groups of adjacent stations to have similar values, but the limited data available do not warrant the publication of the figures involved.

In Text-fig. 4 the numbers caught at 10 metres and the average catches of all the hauls at each station have been plotted together. The cruises have been considered as single straight traverses when in reality the stations are scattered over an area, but such an arrangement allows a convenient comparison between the apparent distribution that would have resulted from the consideration of the 10-metre hauls only and the nearer approximation to the true distribution. We find, as we might expect from the remarks above, that for the Pseudocalanus group, although at some stations the figures are widely discrepant the general picture is quite good. The two main concentrations on Cruise 32 are clearly shown and the overall changes from cruise to cruise are quite apparent. From the limited data available, it appears that Centropages would also be quite adequately sampled by hauls taken at 10 metres. The situation for Temora, on the other hand, is quite the reverse, as on both cruises 28 and 30 the catches at 10 metres would have given a very erroneous impression of the actual distribution. It is true that on the whole the numbers for Temora were lower than those for Pseudocalanus, and so, it might be argued, must be expected to be less reliable, but these are in their turn relatively high when compared with Centropages. There is, however, some reason to suppose that Temora is an exceptional form, and that any conclusions drawn from its distribution should be treated with some reserve. Regarding this Farran (1910, p. 72) wrote: “This species has the habit, more



Text-fig. 4.—Comparative graphs drawn from the data obtained by Savage (1931) on his cruises in the North Sea in the summer and autumn of 1926. At each of the stations shown he took horizontal tow-net hauls at 10-metre intervals from the surface to the bottom. The broken line graph shows the number of copepods caught at a depth of 10 metres only at different stations, and the continuous line graph shows the average catch of all the horizontal hauls at the same stations. For further explanation see text.

marked than in most other copepoda, of forming swarms of great density but limited extent, so that conclusions as to its abundance in any region drawn from a small number of tow-nettings may be very misleading."

There is a second method of approach to the problem of the validity of observations taken at 10 metres—that of using the recorder material. Clearly such questions as whether the vertical distributions of the species vary from season to season or whether the species appear in their true proportions at 10 metres cannot be answered by analysis of information derived from this depth only, but nevertheless it is possible to assess the effect of diurnal migration and this might be expected to be the most serious factor. For this purpose, the parts of each record which were sampled in night and day, during the first 2½ years of the survey, have been separated. As will be seen from the station list (' Bulletin ' No. 2), owing to the regularity of the sailing schedule, practically all the Rotterdam records were taken at night. On a few occasions the machine was not hauled at the eastern end of the tow until a few hours after sunrise, but these parts of records are too few and restricted to give a fair statistical comparison with the night records and can be more conveniently considered individually. In 1933 they consist of the following distances from the eastern ends of the records : In January 20 miles, August 20 miles and December 30 miles ; while the first 15 miles at the western end of the April record were also taken in daylight. It will be seen by reference to the various plates that these day observations, when compared with the rest of the line, were relatively high for all species in both January and December, and that Temora particularly was well represented on the August record during the daytime. In 1934 most records had some part of their eastern end towed during the hours of daylight, and although this was usually restricted to the last 20 or 30 miles, again it is quite clear from the plates that it does not appear less densely populated than the rest of the area which was sampled at night. In fact, by the chance that a number of day samples were taken in the region of the winter coastal concentration, they are on the whole higher than those taken at night. It may be pointed out, however, that the coastal concentration is still clearly shown when sampled at night, for example, on the April record of 1933 and the January record of 1934 with the exception of the last 5 miles.

There is a danger of obtaining a false impression when time and space are as closely correlated as they are on the Rotterdam line. For instance, if the day samples are always taken from an area with a population normally higher, the effect of vertical migration might only be to make the differences between this area and those sampled at night appear less than it should be. This becomes a much less serious possibility on the Bremen line, where, although there is some tendency for night observations to occur more frequently at either end of the record than in the centre, the sailing schedules are much less consistent. On this line in the first 2½ years about 40% of the samples analysed for constituent species (see p. 196) were taken from parts of records towed at night and about 60% during day, the actual numbers being 157 and 234 respectively. The average number of

Pseudocalanus (+ Paracalanus) per mile in the night samples was 69·5 compared with 62·2 in the day, of Temora 28·8 compared with 35·8, and of Acartia 16·0 compared with 23·2; so that taking the three species together more individuals were taken by day than by night. We must bear in mind, however, that a few patches are sufficiently dense to have a considerable biasing effect on the result should they fall more frequently in the day than in the night, and there is, of course, a tendency for denser populations to occur during spring and summer when there are relatively more hours of daylight. To eliminate the effect of this, we can estimate the proportion of records on which the average number of individuals per mile was higher during the night than during the day. In doing this it has been thought wiser to neglect those records that had less than three samples in either category. There remain 22 records; for Pseudocalanus (+ Paracalanus), Temora and Acartia the ratios of higher day and night values are 13 : 9, 12 : 10 and 9 : 13 respectively, or a combined ratio of 34 : 32. This, it may be argued, is sufficiently close to equality for us to conclude that diurnal migration has little if any effect on the apparent distribution of these forms at 10 metres. But before being confident of this we should make sure that these figures are not the result of the fairly regular sailing schedules and the consequent tendency for the night samples to be at either end of the line. Now if the arrangement of the day samples is effectively random in relation to the denser patches of copepods and vertical migration has no considerable effect at this depth, we can assume that each form has an equal chance of being higher in the day or at night on any record. Consequently, as there are three forms, the normal expectancy would be that out of any eight records, all three would be higher in the day on one, two forms would have higher day values on three records, one would be higher in the day on three, while on the remaining record all three forms would have higher night values.[1] If, on the other hand, vertical migration was causing considerable changes in the population at 10 metres, yet its effect was obscured through some correlation between the times of towing and the spatial distribution of the copepods, we should expect a considerably higher proportion of records on which all three forms behave in the same manner, giving in an extreme case a ratio of 4 : 0 : 0 : 4 instead of the 1 : 3 : 3 : 1 mentioned above. We find in fact that the 22 records available are divided into the four categories in the following way: 3, 7, 9 and 3, which is a close approximation to this 1 : 3 : 3 : 1 ratio. Therefore it is improbable that the distribution of day and night samples in the area is responsible for our result, and we can assume that vertical migration is an unimportant factor at this depth and in this area.

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[1] If D and N are used to signify higher values for day and night respectively, the only possible combinations on the eight records are:

.	1	3	3	1
Species “A” .	D	D D N	N N D	N
,, “B” .	D	D N D	N D N	N
,, “C” .	D	N D D	D N N	N

THE DISTRIBUTION OF THE "TOTAL COPEPODA."

The distribution over the $5\frac{1}{2}$-year period will first be considered for each line in turn and then that over the whole area will be discussed.

Rotterdam Line.

It will be seen (Plates LXV and LXVI) that in January, 1933, on the Rotterdam line, the bulk of the Copepoda were taken on the eastern end of the record, but that this had become less pronounced in March and April. During the summer months, with the exception of a central patch in July, the distribution appeared low and relatively even, and remained so until December. The records in December, 1933, and January, 1934, showed that there was again an eastern concentration similar to that found at the beginning of the year, but by March and April this, as in the previous year, had become less marked, and during the summer months the copepods were fairly evenly distributed. The first record in November showed a well-defined concentration near the Dutch coast, and from then until April, 1935, there remained some indication of the eastern preponderance, though this was not so marked as in the winter months of the previous years. From March, 1935, when the numbers found were very low, there was a steady increase in copepods, which was, in April, restricted to the eastern end, but was by June apparent across the line, and in July more were found in the west and centre than in the east. In August and September they remained relatively abundant and evenly distributed, but in October they had become much scarcer on the western half of the line, and decreased generally through November until in December the few that were found were taken near the Dutch coast. The same type of distribution persisted until April, 1936, practically none being found except in the east and there only few. The population remained sparse throughout this summer, though as in previous years there were indications of an extension across the line in June, July and August. By December there had been an improvement in the population on the eastern half of the line, and in fact the numbers taken then were higher than at any other time in the year. This distribution with the copepods restricted to the farther side of the Southern Bight remained fairly constant during the first half of 1937, but by July there were well-marked signs of a return to the usual summer arrangement. Unfortunately although there were two August records, both were short at the western end. The later one appeared to have sampled the edge of a very strong concentration about 50 miles from the English coast, but there was no further indication of this in the subsequent months, during which numbers decreased sharply until December, when practically none were found.

To summarize, as briefly as possible, the copepod distribution on the Rotterdam line, it may be said that in all the winters the copepod population was restricted to the Dutch coast—an arrangement which normally persisted from November until April. It will be seen that in January, 1933, December, 1933, and January, 1934, the copepods were relatively abundant in this region, but that in the following winters, although they were more numerous here than in the west and centre, they never occurred in such large numbers. During the summer months the population was always more evenly spread across the area, and during midsummer there were at times indications of a slight preponderance near the English side. This was pronounced in August, 1937. The most striking features of this series are the extremely poor summer population in 1936 when compared with those of 1935 and 1937, and the apparently progressive decrease of the density of the eastern population during the winter period, from 1932–33 until the end of the survey.

Bremen Line.

By reference to Plates LXVII and LXVIII, which show the distribution of the " total Copepoda " on the Bremen line, it will be seen that broadly the seasonal variation was the same as that on the Rotterdam line. There were no data for the beginning of 1932, but all the records taken in January, February, March and April of 1933–36 showed the tendency for the eastern half of the line to be richer than the western, as during the winters on the Rotterdam line. This was followed, with the exception of 1934, by a marked spring increase in the population, May being in fact on the whole the most prolific month of the year. In 1932, in the absence of any previous records, the copepods appeared most abundant in June. They were at this time situated in two well-defined patches on either side of the centre of the line. During July and August they were much scarcer, but in the latter month more abundant near the English coast than elsewhere ; this was less marked by September, and from October onwards there was a progressive change to the normal winter distribution with the majority at the eastern end. This was followed in May, 1933, by a spring increase, concentrated in a central patch, which appeared to persist in a lesser degree on the part record taken at the beginning of June. In July there was again a concentration near the English coast, as in the previous year, but also a second patch at the other end about the region of the Borkum Light-vessel. Far fewer copepods were taken in the later months of 1933 than in 1932, but as before, there were by November indications of a return to the winter arrangement. As mentioned above, there was no real increase in the spring of 1934, and the eastern restriction in the first three months was less noticeable than in other years, but there was, however, the apparent movement of the centre of concentration to the western side in June. The copepods remained unusually even both in space and time throughout this year, though there was a slight increase in August. It will be seen, however, that although there was no sudden change in the density of population on part of the line in the spring, as in other years, the numbers found throughout the year as a whole were quite as high as normal, and in fact considerably higher in the late summer than in either 1933 or 1937.

In the spring of 1935 the increase was very pronounced. At the beginning of May there appeared an enormous concentration at the eastern end of the line. At the end of the month there was a concentration still here, but, in addition, a very dense patch in the centre. The numbers decreased considerably after this, giving rise to a central arrangement in June, followed by a bimodal distribution in July, with the peaks situated at either end of the line in a manner somewhat similar to that shown in July, 1933. From September onwards there was a general depletion of the population.

The numbers were never high in 1936, when compared with the spring of 1935. In May there was a small but definite increase across the line, but the bulk were still taken in the east. By July the centre of concentration had moved well to the western half of the line, even more markedly so than in previous years, and as before, there was, from September until the end of the year, a gradual reversal to the winter distribution, which became established by the end of November.

During 1937 copepods were very scarce on this line except in May. Unfortunately in January, February and March the records were all short at the eastern end, but, as far as they sampled, they showed no significant indication of the eastern concentration, which normally occurred in the winter. In May, however, there appeared a very dense patch over the eastern half of the line. This had disappeared in the following month, and the numbers remained very low and even from then until the last record, which was taken at the end of November. There was in this year no patch near the English coast in mid-summer as previously, the only possible suggestion of this being a relatively low patch extending some 40 miles from the Outer Dowsing Light-vessel on the first September record.

The main points shown on the Bremen line may be briefly summarized as follows. There was, as on the Rotterdam line, a well-defined and typical winter distribution. From November onwards the copepods appear to be progressively restricted to the eastern end of the line, usually becoming concentrated in the last 40 or 50 miles in January and February. In May there was generally a spring increase, which might appear either in the centre of the line or in the east. Central concentrations in June were followed in 1932, 1933 and 1935 by low numbers in the centre and patches at either end of the line. Again, as on the Rotterdam line, the summer months showed a more even distribution than the winter ones, and a tendency for the higher concentrations to occur towards the English coast. The summer of 1935, as also on the Rotterdam line, is marked by an exceptionally high copepod population, whereas June, July and August of 1937 and August of 1933 show an abnormal poverty for summer months.

Copenhagen Line.

Plates LXIX and LXX show the " total Copepoda " data derived from the Hull-Copenhagen route. There were no satisfactory records for April, May or August in 1933 and no records had been taken prior to June, 1932, but nevertheless it is immediately apparent that numbers were far lower during these summers than during those of the subsequent years. There is, in fact, only a relatively small difference between the numbers taken during the summer and winter in 1932 and 1933. During these two years the distribution remained very even spatially, and with the exception of a slight western preponderance in October, 1932, and September and October, 1933, there is little of significance. It may, however, be worth drawing attention to the small patch situated directly over the south-west patch of the Dogger Bank in March, 1933, for comparison with later years.

From 1934–37 there is a well-defined difference between the summer and winter records. From the late autumn until March there was never more than a very sparse population, and no indication of the eastern concentration found on the two more southerly routes.[1] Throughout the summer, on the other hand, the copepods were relatively abundant. There appeared in April of each year, with the exception of 1936, when there were no data, a general increase over the Dogger Bank, which was usually maintained until August or September, before any marked decrease started to produce the winter scarcity. In this respect the Copenhagen line differed from the Bremen, because in the latter, a pronounced increase in May was generally speaking followed by considerably lower numbers in the next months.

At the end of April, 1934, the increase was well pronounced across the line, but the majority of the copepods were taken in a dense patch over the South-West Patch (*cf.* March, 1933). In the June and August records there was no sign of this patch, but the copepods remain fairly abundant across the line. From September onwards there was steady reduction.

In 1935 the late April record showed again the spring increase as in 1934. In this year, however, it was not so much localized but extended well across the Dogger Bank, although centred about the middle of the line. In May this broad single patch had given place to two large patches situated over either end of the Bank. The area of lower concentration between these two coincided exactly with that part of the line which passes just outside the 20-fathom contour. This can be seen in Plate C, where the 20-fathom contour of the Dogger Bank is included. The June record was unfortunately curtailed on account of fog and only sampled the western half of the line; it revealed, however, a dense patch about 50 miles from the English coast, and high numbers towards its eastern end. The July and August records showed a similar distribution to that found in May; the two patches were slightly less defined to the east and west, but still had their centres of concentration in the same places as before and still showed the region of lower numbers outside the 20-fathom contour. By September and October the distribution was far more even with the numbers decreasing and by December very few remained.

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[1] In this respect it should be remembered that this line usually ended at least 100 miles from the coast. It may be argued that had it extended farther, coastal concentrations similar to those found on the Bremen and Rotterdam lines would have been sampled. This, however, was not found to be so in 1937 when the extra information was available, nor, to anticipate a later report, were there more than the slightest signs in 1938 and 1939.

There was very little data available for the spring of 1936. Unfortunately in March, April, May and July a series of mechanical defects caused the records to be short. In the first three of these months only about 60 miles were satisfactorily sampled. The only facts apparent from these part records were that there was an increase at the extreme eastern end of the line from April to May, giving rise to a considerable concentration here in early July. Further, there were relatively few copepods over the Dogger Bank in the latter month. A record in August showed no indications of the high numbers over the Bank as in 1935, but rather that the bulk of the copepods were situated to the west and over its eastern end. By November the copepods were again scarce.

The spring increase in numbers was again apparent in April, 1937. There was only a slight increase over the major part of the line, but a dense concentration only a few miles broad was found about 60 miles from the English coast just west of the South-West Patch. At the beginning of May there was a further increase on the central and eastern parts of the line, slightly larger numbers being taken over the north-eastern end of the Bank than elsewhere. The following month there were similar numbers over the north-eastern end, but to the east and west of this two very dense concentrations had appeared. By July there were still two points of concentration comparable to those in June, but both further west. In August the numbers were lower in the area sampled, but the record stopped 90 miles short at the English end. During October, November and December very few copepods were taken, and it seemed that the winter distribution had appeared earlier than in previous years.

From July until the end of December the normal length of the Copenhagen-Hull tow was extended by 100 miles. This extra distance sampled revealed very little in these six months except a third centre of concentration in July.

Considering the results obtained on the Copenhagen line as a whole, one sees that 1932 and 1933 are probably comparable in their relative scarcity of copepods, that 1935 and 1937 are similar in their abundance, and that 1934 lies as an intermediate between the two pairs. In view of this it is interesting to note that there is a marked similarity in the seasonal spatial arrangement found in both 1935 and 1937. Early in both years there appeared a very wide patch centred over the Dogger, which gave place in subsequent months to two centres of concentration, which persisted for two months in 1937 and four months in 1935. This suggests some relationship between the density of the population in this area and the factors governing its spatial distribution. A series of short records in 1936 provide only limited data for the spring of that year and prevent comparison with other years, but the July and August records indicate that it may have been at least as successful as 1934.

Esbjerg Line.

In 1937 the Esbjerg line was instituted regularly. It was run from the Sunk Light-vessel to the Graadyb Light-vessel. The results obtained therefrom are presented on Plate XCII. It afforded a useful check for the Bremen and Rotterdam lines, and also gave some idea of the distribution across the Heligoland Bight.

It will be seen that the April record showed the winter arrangement of copepods which might be expected from the consideration of these other lines. There was a general low distribution with a slight preponderance towards the north-eastern end of the line in that part of the Bight sampled by the eastern end of the Bremen records. In May there was a very marked increase in this region, which, as has already been pointed out, was also revealed by the Bremen record for this month. This concentration stretched well up towards the Danish coast. The June record was short at both ends, but the 160 miles that were valid indicated that the centre of concentration was by this time south-west of the centre of the line, that the numbers were generally lower, and that the really dense patch found in the east in the previous month had moved away from this area or had died down.

The records for July and August showed relatively even distributions along their lengths, although a number of minor fluctuations were found. Numerically the population appeared slightly lower than in the two preceding months, but nevertheless was surprisingly high when compared with the contemporary Bremen records. It may be remembered that during this period very few copepods were found on the Bremen line, whereas the numbers on the Rotterdam records were quite as high as usual.

From September until the end of the year all the Esbjerg records caught very few copepods and the general sparse winter arrangement appeared to have returned.

Distribution in Area as a Whole.

It is hoped that by considering the fluctuations on the four lines together a better idea may be obtained of the general distribution of the copepods in the area. To facilitate this the graphs of the various records have been arranged month by month on a series of small maps. Each record is placed in its correct geographical position (see Plates XCIV–CVI).

It is convenient for this purpose to divide the year into four quarters and treat these independently.

During the first quarter, January, February and March, it will be seen that spatially the population is arranged in a similar manner in each year. There appears to be a band of relatively high concentration off the Dutch coast and following its contour. There is in different years a varying degree of westward extension of this community; for example, it is less pronounced in 1934 on the Bremen line than in other years, but, nevertheless, it would seem to be a very consistent feature of the winter distribution. Over the rest of the area, during these months the numbers are low and even. It must be borne in mind that there is no absolute evidence of continuity between the patches of copepods found at the eastern ends of the Bremen and Rotterdam lines, but in view of their persistence for several months of each year, they may be considered indicative of a general coastal concentration stretching at least between the points of observation.

The next quarter is characterized by an increase in the density of the population over the northern part of the area. The actual timing of the arrival of this increase is made difficult by the fact that April and May have been, throughout the survey, months in which, for some unknown reason, there has been a far higher incidence of unsatisfactory records than in any others. However, in the three years 1934, 1935 and 1937, in which data for April was available on the Copenhagen line, there were signs of a change from the general low winter distribution. In 1934 there appeared a dense patch over the South-West Patch, in 1935 a general increase over the Dogger Bank, and in 1937 a patch just to the west of the edge of the Bank. On the Bremen line satisfactory April records were only obtained in 1935 and 1936, and whereas there was an enormous concentration in the east on the former there was no indication of this on the latter. If, however, the maps for the months of May are considered there is evidence leading to the conclusion that this synchronous increase over the Dogger Bank and at the eastern end of the Bremen line is quite usual in the spring. It will be seen that the general picture for May, 1937, is rather similar to that shown for April, 1935, and by reference to the dates in 1935 it will be noticed that all the records were taken near the end of this month. Further, although there was no change found on the Bremen line by the middle of April, 1936, there was a higher concentration in May, and this was again more pronounced towards the eastern end. Generally speaking there is a tendency for the bulk of the copepods to be concentrated much nearer the centre of the area during this quarter than during the first.

The July-September quarter reflects the success or failure of the spring increase in population. By this time the copepods have become fairly evenly spread over the area and the patchiness which is typical of the spring months is less marked. It can, however, be a very lean period, as for example in 1933. One comparatively consistent characteristic of these three months is the tendency towards a bimodal distribution on the Bremen line. A region of lower concentration in the centre of the line appears in some degree at some time during the quarter in every year except 1936. It was most pronounced in July and August, 1935, but was also noticeable in July, 1932, July, 1933, August, 1934, and August and September, 1937.

The last quarter shows a transition from this relatively plentiful summer stock to sparse winter distribution and the tendency to the coastal concentration off Holland.

Without doubt the most striking feature of this series is the extent to which the density of the copepod population can vary from year to year. Although there is some variation in the success of the winter populations, that of 1932–

1933 being particularly good, these are insignificant when compared with the differences between the spring and summer months during the five and a half years. It is difficult to assess 1932, as no records were taken before June, but there can be little doubt that, if the July to September periods are compared, it was a more successful season than 1933. Unfortunately we are very short of information in April and May of 1933, but with the exception of the winter coastal concentrations, the May Bremen record was the only one that showed any indication of high numbers. 1934 showed an improvement. Again there was a run of bad luck with the spring records, but the June, July and August maps show clearly that the population was stronger than in the previous year and probably than in 1932. In April and May, 1935, after a comparatively poor winter, really high numbers of copepods were taken for the first time. These concentrations on the Copenhagen and Bremen lines were not only denser than any found before, but they were widespread when compared with the restricted patches found in May, 1933, and April, 1934. Further, in this year, the larger catches continued well into the autumn, and until August they remained higher than those in the most successful months of the earlier years. Although once again the spring information was spoilt by a series of short Copenhagen runs, 1936 obviously fell well below the 1935 level, but nevertheless appeared slightly more successful than 1934. Then following another lean winter period, there was between April and May, 1937, another sudden increase in the population very similar to that of 1935. Although the high numbers did not persist on the Bremen line as long as they did in the former year, the northern part of the area was still as successful in July.

With the copepods forming an important link in the food chain, fluctuations of this magnitude must almost inevitably be reflected in the general ecology of the sea. Almost certainly such changes will play a big part in determining the success or failure of the fry of many of the marketable fish which depend on the smaller copepods for a large part of their diet, and it is quite probable that a long-term study of such gross changes, especially over an extended area, will be of great assistance in forecasting the variations in the commercial fisheries.

PART II.—THE DISTRIBUTION OF THE SPECIES OF COPEPODA.

INTRODUCTION.

As has been pointed out earlier in this Report, during the first years of the survey it was only possible to identify and count the "total Copepoda" as a combined group and add to this an estimate of the number of larger species. Although knowledge of the seasonal production of the whole copepod population and more especially of the factors controlling long-term fluctuations in its success might well, with careful interpretation, be useful in helping to forecast the variations in the commercial fisheries, it is clear that an understanding of the ecology of the components of the population would make this a great deal more probable. Whereas there may be over-riding physical conditions controlling the entire stock, there will also be other minor factors affecting only those parts of it that have particular ecological idiosyncrasies. There is some evidence that as a result of selective feeding, some fish may be more dependent on certain copepod species than others. For example, Lebour (1919) described copepods as the chief food of larval and post-larval fish, and pointed out that although most fish eat one or more of the four commonest species, *Pseudocalanus elongatus*, *Temora longicornis*, *Acartia clausi* and *Calanus finmarchicus*, there is usually in each case a definite selection. The whiting up to 9 mm. show a preference for Pseudocalanus, but in the spring, when this species is less common, will take Acartia or Calanus but rarely Temora, even if it is very abundant. The soles and the dab eat Temora but hardly ever Pseudocalanus, while *Scophthalmus norvegicus* appears to select Pseudocalanus and Acartia. Again the particular importance of the single species, *Pseudocalanus elongatus*, in the southern North Sea was stressed by Hardy (1924). He showed that in that area the post-larval herring are almost entirely dependent on this species for food during approximately three months of their development, and suggested that variations in its success from year to year might play some part in controlling the fluctuations in the numbers of adult herring in subsequent years. It is also clear from his investigations that whereas older herring (*i.e.* those over 30 mm.) might be able to make up a deficiency of Pseudocalanus by taking, for example, Temora if it was more abundant, the smaller individuals would be unable to do so on account of its larger size.

Such considerations made it clear that it would be valuable to return to the material that had been scraped from the rolls and to attempt as detailed an analysis as possible. An opportunity to do this did not present itself until 1936, and then the time available prohibited the examination of more than a fraction of the samples available.

METHOD OF ANALYSIS.

For the purpose of this survey one record per month has been analysed for constituent species on the Bremen and Rotterdam lines and one every other month on the Copenhagen line whenever this was possible. In months when more than one record had been taken on a line, the longest was selected and an effort was made to select those rolls for analysis which were as evenly spaced in time as possible. At first every fifth tube was analysed, giving an observation at about every 10 miles along the length of the line, but after half the Bremen records had been completed it was found to be necessary to reduce the number of tubes analysed by half, so that from then on data for the relative abundance of the constituent species were only taken approximately every 20 miles. As described in 'Bulletin' No. 1, after the first few months of 1936 the rolls were divided up into units or "blocks" representing 10 miles of tow. Every second "block" was analysed for the copepod species, so that from this point the observations are at exactly 20-mile intervals. It should be noted, however, that whereas previously each analysed sample only contained the plankton from approximately 2 of the 20 miles it was taken to represent, it now contained the plankton from 10 miles.[1] The scraping technique has been referred to earlier in this report. Briefly it was as follows: each 2-in. division of silk was thoroughly scraped with a razor-blade, and plankton from it was preserved in a tube containing 4 per cent. neutral formalin, to await any further identification or confirmation of the silk estimations that might be deemed necessary. During the earlier part of the survey the plankton from each division (*i.e.* 2 in.) was kept separately, but from the beginning of 1936 a number of divisions were added together, so that each tube represented the catch from 10 miles of tow (see p. 176).

The procedure adopted with each tube analysed was as follows: The tube contents were washed out into a round dish 4·8 cm. in diameter. Using a low-powered lens, a count was made of all the larger genera, such as Calanus, Labidocera, Metridia and Candacia to confirm the similar counts made on the rolls, and to provide data for those rolls which had been analysed before the practice of counting these on the silk was adopted and for those on which the abundance or type of plankton had made this count unreliable.

After the dish had been thoroughly shaken to give an even distribution of plankton over its area, it was placed on a "Murray" long range mechanical stage and traverses were made across two diameters at right angles to each other. The optical equipment consisted of a $\frac{2}{3}$-in. objective and a × 6 ocular. It was found by experiment that two such traverses included in their field a close approximation to $\frac{1}{8}$ of the area of the dish. Again, as in the roll, only those copepods showing the proximal ends of their antennae in the field were counted, and the number seen was multiplied by eight to give an estimate of the number present in the sample removed from the silk by scraping. The object of this estimation was primarily to give some measure of the normal loss due to the scraping operation. It was obvious at once that there must be some loss, and in the probability of this loss being more pronounced for the smaller or more fragile species, it seemed advisable to base any figures of the relative abundance of different groups that were found in the tube on the number of individuals that were present in that tube rather than on the number that had been on the roll. It gave, however, some insight into the accuracy of the sub-sampling method used in estimating the copepoda on the roll. Although in a number of instances there was a disturbing discrepancy between the roll and the tube estimations of the number of copepods on any particular section, it was found that if they were all considered together they gave a correlation coefficient of ·89, which is felt to fall well within the limits of experimental accuracy normally expected or required in ecological work. The average loss from the roll to tube was found to be slightly below 15%, and there is some evidence that this was chiefly due to the single genus Oithona.

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[1] Following further modifications to the internal mechanism, it has become possible to identify the individual copepods while they are still on the silk.

The dish was next traversed up and down progressively until 50 copepods had been seen and as many of these as possible identified. In order to avoid identifying as two individuals two parts of a single mutilated specimen, it was decided to include in the 50 copepods only those which had the anterior end present. In the tubes containing less than 50 individuals a proportion exceeding half of those present was identified.

The descriptions in G. O. Sars' 'Crustacea of Norway' were used in identification throughout and the material was divided into the following species or groups :

- *Calanus finmarchicus* (Gunnerus)
  - over 2 mm. in length.
  - under 2 mm. in length.
- Pseudocalanus
  - *Paracalanus parvus* (Claus).
  - *Pseudocalanus elongatus* Boeck.
- *Centropages typicus* Kröyer.
- *Centropages hamatus* (Lilljeborg).
- *Isias clavipes* Boeck.
- *Temora longicornis* (Müller).
- *Metridia lucens* Boeck.
- *Candacia armata* Boeck.
- *Anomalocera patersoni* Templeton.
- *Labidocera wollastoni* Lubbock.
- *Parapontella brevicornis* (Lubbock).
- Acartia
  - *Acartia longiremis* (Lilljeborg).
  - *Acartia clausi* Giesbrecht.
- Harpacticoidea.
- Oithona spp.[1]
- *Corycaeus anglicus* Lubbock.

In the majority of the samples the Copepoda were in a very bad condition, the bulk of them being completely flattened and often fragmented, and consequently a certain number of genera and species had to be grouped together. It is hoped, however, that in the future with the improved mechanism this will be avoided and a more complete identification will be practicable.

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[1] As explained on the next page a treatment of the genus Oithona has been abandoned owing to the unsatisfactory nature of the material.

It was found to be very difficult to separate *Paracalanus parvus* from *Pseudocalanus elongatus*, and adopting the recommendation of Gran, Hentschel and Russell (1936), they have been joined in a single category. Wherever possible some gross estimation of their proportions was made in the hope that any broad spatial or seasonal variation in their relative abundance might be apparent, and some indication might be gained as to the desirability of attempting to separate them in the future.

Acartia longiremis and *A. Clausi* were also combined, because the proportion found squashed in such a way that their diagnostic features were obscured was too large to warrant the time necessary to identify the relatively low numbers of identifiable individuals.

A certain number of Harpacticoidea were taken on the rolls. The majority were copepodid stages of Ectinosoma and Microsetella, but no estimation of the actual abundance of these or other genera was made. A reference to the occurrence of *Alteutha interrupta* will be found on p. 233.

Of the Cyclopoidea, only *Corycaeus anglicus* was identified specifically. The genus Oithona was not subdivided, because from the start it was apparent that the method was unsuitable for its study. There was a tendency for individuals to become embedded in the meshes of the silk, so that a disproportionately large number were left on the silk during the scraping, and it appeared far more susceptible to mutilation during this process than the larger and more robust genera. There were, in addition, a number of cyclopoid copepodid stages. A description of the distribution of these and of the genus Oithona has been abandoned owing to this unsatisfactory nature of the material.

If an attempt had been made to identify every individual seen specifically the percentage of unidentifiable copepods would have increased considerably, reaching a figure as high as 50% or 60% in some samples. While most of the species by the nature of their diagnostics are rarely damaged beyond recognition, the separation of *Acartia clausi* from *A. longiremis* and *Paracalanus parvus* from *Pseudocalanus elongatus* is dependent on diagnostics less pronounced and more easily destroyed by the crushing to which the Recorder material is subjected. So in order to keep the number of unidentified individuals as low as possible and to avoid obtaining disproportionately low values for Paracalanus, Pseudocalanus and Acartia, it was thought better to combine them into the two groups described above at the expense of detailed information.

Limitations of the Method.

Before considering the distribution of various species some further assessment of the validity of the method should be made.

The analysis of the individual species differed from the general recorder technique in a number of ways, which must be expected to cause some loss in accuracy and detail.

The first difference was that whereas the examination of phytoplankton, the " total Copepoda," and most other organisms was made on the silk, that of the copepod species was made from the plankton scraped from it. By comparing all the tube estimates of the total copepoda with the corresponding silk values, it was found that the average loss through scraping was about 15%. In isolated cases the discrepancy between tube and roll was much higher, but such exceptions must be expected when comparing two figures both susceptible to sampling errors. As stated above, the figure for any species was based on the total number found in the scrapings and not on the number estimated on the silk. This policy, although eliminating the effect of the disproportionately large loss of the genus Oithona, did open the possibility of an error due to a varying success of the scraping technique at different times. There was in fact little doubt that whereas the presence of Phaeocystis allowed almost every individual to be removed, when little other than copepods were on the silk a proportion higher than the average value of 15% might be left embedded in the meshes or rendered completely unrecognizable. However, usually Phaeocystis in quantity made an estimate of the number of copepods in the tube impossible, and so for want of a better method the roll totals, less 15%, were used in these cases and so cancelled the effect of the more successful scraping. It is clear that the variations in the efficiency of the removal of the plankton were very small when compared with the differences in numbers of individuals in both space and time, and so can safely be neglected.

For reasons stated earlier, it was only possible to analyse one division out of ten on the records examined for the individual species. There were exceptions to this, namely, that on every other Bremen record from 1932–35 every fifth division was taken, and that during the later part of 1936 and all 1937 each tube contained the plankton scraped from a length of silk equivalent to 10 miles of sampling. In order to interpret the results obtained by this method, it is necessary to consider this single observation in ten divisions, which may represent a distance varying between 12 and 25 miles, as typical of that distance. It is, therefore, important in assessing the validity of the method to determine to what extent we are entitled to do this.

Lucas (' Bulletin' No. 3, p. 83) raised this point when comparing the efficiency of the recorder with the more conventional method of taking vertical hauls at approximately 20-mile intervals. He showed that by taking a typical record and considering the various combinations of every tenth division, very different ideas of the distribution of *Rhizosolenia styliformis* might have been obtained. A certain patch might have appeared as much as ten times more dense in one series than another. While such differences may be fairly common in the phytoplankton material, they are not likely to be so for the copepoda, because they are obviously dependent on major changes in concentration occurring twice within 20 miles or, in other words, on the existence of dense patches not more than 20 miles in extent, and by reference to the "Total Copepoda" data it will be seen that such are exceptional, and it will be shown later that it is unlikely that they occur often with the individual species.

The point we wish to determine is to what extent we must expect the population to vary within the distance sampled by ten recorder divisions. Probably the simplest and most convenient method of doing this is that adopted by Gardiner (1931) in his comparison of successive vertical hauls taken by Savage (1931). It may be recalled that he divided the observations into arbitrary "groups," defined by the postulation that all the observations in any group were included in a certain period of time. He then took the average of these observations as the best measure available of the plankton sampled by them, and expressed the deviation of each observation from this "group mean" as a percentage of it. So he obtained a measure of the frequency with which any percentage deviation from the average was likely to occur. For our purpose we can take the estimate for "total Copepoda" in ten successive recorder divisions as a "group" and find how often the estimate made from a single division in a group will be sufficiently atypical to be misleading.

The records for the first six months of 1935 were used, as they appeared to include a good selection of the various types of distribution found during the survey. The policy adopted was to start with the first division of each record, and take successive groups of ten divisions until the end of the line. In Table I a sample group is set out to make the procedure quite clear.

TABLE I.—*A Sample Group Showing the Method Adopted in Estimating the Percentage Deviations of the Observations in a Group of Ten Divisions.*[1]

No. of division.	Estimated number of copepods ÷ 10.	Deviations from group mean (259).	$\frac{\text{Deviation} \times 100.}{\text{Group mean.}}$
51	314	+ 55	21%
52	278	+ 19	7%
53	274	+ 15	6%
54	286	+ 27	10%
55	290	+ 31	12%
56	212	− 47	18%
57	232	− 27	10%
58	206	− 53	17%
59	246	− 13	5%
60	256	− 3	1%

Group mean = 259

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[1] All estimates refer to catches with the earlier aperture fitted to the recorder, *i.e.* $\frac{3}{4}$-in. square. They appear in the Plates expressed at $\frac{4}{9}$ths of the above values to make them comparable with the later catches taken with a $\frac{1}{2}$-in. square aperture (see p. 176). For obvious reasons it would have been unfair to make this correction in the tables.

The period tested included 55 groups, giving 550 observations. These are arranged in Table II, so that the frequency with which any percentage deviation occurred in any range of mean values can be seen at a glance. There is a higher incidence of larger deviations when the mean values are low. This is to be expected, but the occasional estimation of either 0 or 200 copepods when the value should have been 100 is not disturbing, as all numbers of this order fall into the category

TABLE II.—*Showing the Frequency Distribution of the Percentage Deviations (Signs Ignored) in the Various Ranges of Group Means.*[1]

	Group means ·|· 10.										
% deviation from group mean	0–9.	10–19.	20–29.	30–39.	40–49.	50–59.	60–69.	70–79.	80–89.	90–99.	>99.
0–9	34	13	8	13	3	6	2	3	4	4	15
10–19	8	9	10	19	4	3	2	2	3	3	23
20–29	34	11	14	13	..	5	..	2	9	1	13
30–39	39	7	4	7	..	3	4	1	3	2	10
40–49	10	10	2	2	2	2	2	1	3	..	4
50–59	38	4	6	5	..	..	..	..	2	..	1
60–69	12	5	4	1	1	1	..	..	2	..	2
70–79	13	2	..	..	..	..	..	..	1	..	2
80–89	..	5	..	..	..	..	..	..	1	..	..
90–99	..	..	..	..	..	..	..	..	1	..	..
>99	22	4	2	..	..	..	..	1	1	..	..

[1] See footnote to Table I.

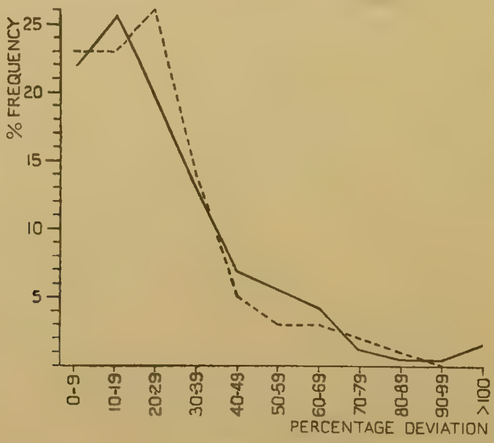
TABLE III.—*Showing the Frequency Distribution of the Percentage Deviations of All Estimates and of only those from Groups with Means Exceeding* 19.[1]

	All estimates.			Estimates from groups with means > 19.		
% deviation from group mean	Frequency.	% Frequency.	% Cumulative frequency.	Frequency.	% Frequency.	% Cumulative frequency.
0–9	105	19·1	19·1	58	21·5	21·5
10–19	86	15·6	34·7	69	25·5	47·0
20–29	102	18·6	53·3	57	21·1	68·1
30–39	80	14·5	67·8	34	12·6	80·7
40–49	38	6·9	74·7	18	6·6	87·3
50–59	56	10·2	84·9	14	5·2	92·5
60–69	28	5·1	90·0	11	4·1	96·6
70–79	18	3·3	93·3	3	1·1	97·7
80–89	6	1·1	94·4	1	·4	98·1
90–99	1	·2	94·6	1	·4	98·5
>99	30	5·4	100·0	4	1·5	100·0

[1] See footnote to Table I.

of " few present " (see footnote to Table I). It will be seen, however, from the summarized results in Table III that if we neglect areas with mean populations of this order, we need only expect one observation in every five to differ by more than plus or minus 40% from the average of the ten observations it is taken to represent.

In Text-fig. 5 the frequency of percentage deviations are plotted together with those found by Gardiner (1931). The continuous line graph shows the percentage frequency with which the analysis of one recorder division in a group of ten differs from the mean of the group by various percentages when the mean exceeds 20 (see Table III). The broken line graph, plotted from the data of Gardiner, shows the percentage frequency with which the estimated numbers of Calanus, Pseudocalanus and Temora per metre caught in vertical hauls with an International Net differ from the mean of his " group " of such hauls taken over a restricted area. His definition of a " group " was that it contained at least five hauls taken within an hour from the drifting boat. It is impossible to estimate how far the boat would drift relative to the water column beneath it in one hour, but in view of the favourable weather conditions prevailing during the experiments, it can only have been a matter of yards. There is further evidence from the work of Herdman (1920), Gardiner and Graham (1925) and Winsor and Walford (1936), which suggests that fluctuations of this order in adjacent hauls are inevitable in the sampling techniques, regardless of how close together they are taken ; or that they are the result of a " patchiness " inherent in distribution of plankton in the sea.



TEXT-FIG. 5.—For explanation see accompanying text.

We are then faced with the apparently anomalous conclusion that a single horizontal haul with the Recorder gives a sample as typical of the plankton over a distance of 12 to 25 miles, as a vertical haul is of other vertical hauls only a few yards away from it. This would be easily explained if we could assume that the normal distribution of the plankton was far more even from the surface to the bottom than it was in the horizontal plane. Then the vertical hauls would be subjected to a degree of patchiness that would not affect the horizontal ones, but this seems improbable in view of the very patchy vertical distributions found by Savage (1931), which we show in Text-figs. 2 and 3. A more probable explanation lies in the length of the hauls in the various methods of sampling. The vertical hauls only sample a column of water about 50 metres long, the conventional 10-minute horizontal hauls about $\frac{1}{4}$ of a mile, while in the Recorder each sample includes plankton from about 2 miles of water. This longer haul of the Recorder must have a considerable smoothing effect on the numbers found. A single division samples a distance equivalent to approximately four conventional horizontal hauls taken consecutively, and in doing so probably samples both high and low concentrations of plankton giving a smoothed value over the two miles, and we have seen from Gardiner's results that the population may vary considerably in shorter distances than this, at least when estimated with vertical hauls. The comparison of successive half-mile horizontal hauls taken on the *Discovery* Expedition shows in the deeper waters of the Antarctic (Hardy and Gunther, 1935, p. 255 *et seq.*) how large this smoothing effect would be in that area.

It would seem probable, however, that only on rare occasions will the division selected for complete analysis give a very misleading impression of the plankton it is taken to represent. In fact the suggestion is that it will give as fair a picture of the 12 to 25 miles as the vertical haul does of the area immediately around it.

It is thought probable that further consideration of the recorder material along these lines, augmented by some designed experiments using a reduced winding speed of silk, should be very useful in giving a better picture of the degree of patchiness in the sea and a better idea of the validity of isolated samples. It is hoped that such a study will be possible in the future.

Further confidence in the method is given by the detailed analysis of a series of weekly records in the autumn of 1937 (see p. 224), when, although the catches of some forms were low, the agreement between successive records is too consistent to be accounted for by chance.

ARRANGEMENT OF THE DATA.

Graphs have been compiled for the main species and categories of copepods identified on each record that was fully analysed, in a similar manner to that used for the " total Copepoda " (see p. 177). As before, the graph is a measure of density of population plotted above a mile scale which stretches between the relevant lightships. In the case of the " total Copepoda " these graphs were arranged in two ways—as a chronological series for each route in turn to facilitate the comparison of the five years, and secondly on a number of maps to give an idea of the changes occurring over the whole area. The space available prohibits the publication of both series for all the forms identified, so it is thought advisable to use only the annual series for the more common copepods, such as the Paracalanus-Pseudocalanus group, Temora and Acartia, which it will be seen together constitute a very large proportion of the population and each of which follows fairly closely the spatial distribution of the total. These will be found on Plates LXXI–LXXXVIII and XCII–XCIII. It is comparatively easy to relate the various peaks in their distribution which are shown in the annual series with the corresponding patches on the map arrangement shown for the " total Copepods."

Isias clavipes and *Corycaeus anglicus*, on the other hand, were only found during a part of each year, were always scarce, and their relative abundance bore very little relationship to the fluctuations of the total population. They both showed characteristic and somewhat restricted spatial distributions, which are best illustrated by the map arrangement. They have been combined on a single series (Plates CXIX–CXXV). The comparison between their densities in the various years is not difficult from this arrangement because in each case there are only two or three months to be considered.

The significance of the two species of Centropages is thought, for reasons that will be given later, to warrant both methods of presentation. They can be conveniently plotted together and the two sets will be found on Plates LXXXIX–XCI and CVII–CXVIII as the annual series and maps respectively.

Calanus finmarchicus is not dealt with in this report. As has been mentioned before, the Recorder Survey was at first planned to investigate only the broadest changes in the plankton, and more particularly those changes which might have direct economic application to the fisheries. Originally the copepoda were treated as a single category on the assumption that their total number was an indication of the production of food available for the plankton-feeding fish. The comparison of the Indicator discs with herring catches (Hardy, Lucas, Henderson and Fraser, 1936), showed clearly that the relatively large size of Calanus made it the key copepod as far as the herring was concerned, and as was then pointed out the total copepod population could only be assessed as " available food " if the various constituent species were considered in relation to their respective sizes. At this stage it appeared impossible to analyse the recorder rolls in detail. As stated on p. 176 it was, however, thought possible to make a very rough estimate of the number of the larger stages of Calanus and other similar sized forms, such as Anomalocera, Labidocera, Candacia and Metridia, on the rare occasions when they appeared, by counting them on the silk with the naked eye, and so at least to separate the larger and smaller forms. The criterion used for a " larger Calanus " was that the length of its metasome exceeded 2 mm. This was only to be used as a rough guide and no actual measurement of individuals was undertaken. There can, in fact, be little doubt that the criterion varied both with the worker and at different times, and for this and a number of other reasons the estimates have since proved unsatisfactory. In view of the particular importance of this species it has been thought wiser to return to the material for more detailed information regarding both its total numbers and the proportions of the various copepodid stages. In the near future this revised data combined with the findings from the extended area sampled in 1938 and 1939 will be the subject of a report on the ecology of Calanus in the Southern North Sea from 1932–1939.

A generalized picture of the distribution of *Candacia armata*, *Metridia lucens* and *Parapontella brevicornis* will be found in Text-figs. 10 and 11. These species never appeared in appreciable numbers, so the arrangement used for the commoner forms was unsatisfactory for them. A more summarized picture was required to show merely the time and position of their various occurrences.

A diagram comparing the numbers of Labidocera caught in the various years is included in Text-fig. 9.

It is felt that the Plates show the general trends in the distribution clearly. There is in addition a description of the variations seen in the commoner forms (immediately following). It is suggested, however, that unless the reader is interested in the detail of these variations he should neglect this and refer to the more generalized sections following it which include a summarized account.

THE DISTRIBUTION OF *Paracalanus parvus* AND *Pseudocalanus elongatus*.

As has been explained in the introductory section, *Paracalanus parvus* and *Pseudocalanus elongatus* have been combined for this report into a single category. Together they constituted by far the greater proportion of the whole population during the major part of the year, so it is inevitable that any description of their distribution will follow fairly closely that of the total copepoda. In view of this it would only appear necessary to draw attention to a few of the more striking points.

It will be seen from Plates LXXI and LXXII that on the Rotterdam line Para- and Pseudocalanus exhibit the swing from west to east already pointed out for the Copepoda as a whole. Whereas there were pronounced concentrations on the eastern half of the line from January to the beginning of April, 1933, from December, 1933, to January, 1934, and from December, 1936, to March, 1937, there were in September and October, 1933, September, 1934, and October, 1937, definite preponderances on the western half. It is important to note that the winter months may be more productive than the summer. In fact the concentrations off the Dutch coast in January of 1933 and of 1934 were as dense as any found with the solitary exception of the western patch on the October record in 1933; and in 1936, following three of the poorest months of the survey, there is a pronounced increase in early December which persists until the March of 1937. This, together with the fact that during the period December, 1933, to January, 1934, the numbers were higher than those in November, 1933, indicates that there may be a considerable recruitment of the winter population either due to late autumn breeding or the accumulation of individuals carried here from some other region. There is some evidence awaiting confirmation in future years that the winter concentration is composed almost entirely of Paracalanus, whereas in the summer the more northerly form Pseudocalanus is predominant.

In Plates LXXIII and LXXIV are arranged the data for the Paracalanus-Pseudocalanus group derived from the Bremen records. It will be seen that here again its distribution follows closely that of the " total Copepoda " in as much as there is an easterly tendency during the winter and a westerly one during the summer.

The most striking point of the series is the enormous production in 1935. Throughout the summer of this year the numbers found were far higher than at any other time on this route. From January to March there was a low and fairly even distribution, with indications of the eastern preponderance not well pronounced. Towards the end of April, however, an enormous concentration had appeared in the east. A similar patch remained in May, separated by a narrow region of low numbers from a second equally dense patch over the centre of the line. The central patch persisted to some extent for the next three months, being reduced in June and July, but increasing again in August. In June there was no sign of the eastern one, but one appeared again as quite a dense concentration in July and the August record, although short, again suggests its presence.

It is interesting to note that the group was more abundant on the eastern end of the line in January and February in 1933 and 1934 than it was in these months in the later years. This was also found to be the case on the Rotterdam line, and so adds to the evidence already found in the consideration of the " total Copepoda " that there is some spatial continuity in the winter coastal population.

As has been stated earlier, fewer records were analysed for constituent species on the Copenhagen line than on the two more southerly routes. It will be seen, however, that from Plates LXXV and LXXVI a certain number of generalizations can be made. The summer months of 1935 and 1937 appear to be the outstandingly successful periods for the Paracalanus-Pseudocalanus group. In both May and July, 1935, there were two very dense patches covering the bulk of the line. In 1937 a very rich population in May, stretching across the Dogger Bank region, gave way in June to two more restricted patches at either end of the line. January, 1935, January and February, 1936, and from September to the end of 1937 appear to be periods of abnormally low numbers.

In 1937 information was available from the fourth route from the Thames estuary to Esbjerg. In the absence of earlier data this route has little comparative significance, but, as will be seen from Plate XCII, the high numbers taken on the eastern half of the June record help to delimit the very dense patch sampled by the Copenhagen line and the eastern end of the Bremen line in this month. Again on this line the period from September to the end of 1937 appeared to be a particularly poor one for Para- and Pseudocalanus.

Attention may be drawn to the fact that at no point in this series is there any indication of more than one increase in the Para- and Pseudocalanus population during the year. The low winter distribution gives place to the more abundant summer one quite suddenly in April or May, and from that time there is a steady decrease to the autumn and following winter.

THE DISTRIBUTION OF *Temora longicornis.*

In Plates LXXVII and LXXVIII are arranged the data for the species *Temora longicornis* on the Rotterdam line. This species also reflects the distribution of the "total Copepoda," but to a lesser degree than the Paracalanus-Pseudocalanus group described above. The densest concentration of Temora was found on the centre of a record taken in late July, 1933, and it would appear that the months June and July are normally periods of relative abundance for the species in this region. The difference between these months and the subsequent ones is more pronounced than it is for Pseudocalanus. The records for January and December in 1933 and 1934, December, 1936, and February and March in 1937 show that Temora is well represented in the winter population off the Dutch coast.

On the Bremen line, Plates LXXIX and LXXX, Temora was again found to be abundant during the summer, the more successful months being August, 1932, May and July, 1933, May, 1935, June and July, 1936, and May, 1937. There were even higher numbers across the line in November, 1932, compared with the few taken after August or September in the other years. On the whole it may be said that the Temora population fluctuated far less from year to year than the Paracalanus-Pseudocalanus group. Although fairly high numbers were found in the mid-summer of 1935 and May, 1937, the difference between these and the normal density is not so marked.

It will be seen that the species shows plainly in every year except 1937 the apparent movement of the centre of concentration along the line from east to west and back again.

With the exception of the May records in 1935 and 1937 the numbers of Temora on the Copenhagen line were very low (see Plates LXXXI and LXXXII). There was a patch situated over the south-western edge of the Dogger Bank at the end of April, 1934, which suggests, together with the 1935 and 1937 observations, that this is the most successful month in this region, but it is clear that the species is generally more abundant on the two more southerly routes.

THE DISTRIBUTION OF ACARTIA.

In Plates LXXXIII and LXXXIV the data for Acartia are presented. As stated above, it was found to be impossible to identify the species in the mutilated material in sufficient cases to warrant the time required. The impression gained is that *Acartia clausi* was far more common than *Acartia longiremis* and that *Acartia discaudata* occurred only very spasmodically, if at all.

On the Rotterdam line Acartia was not very well represented in the three winter periods successful for the forms mentioned above, *i.e.* January, 1933, December, 1933 and January, 1934, and February and March, 1937. It was more abundant then than in the winter months of 1935 and 1936, but the difference is not pronounced as in other species.

A slight increase in the density of population appeared about July in each year, while in 1935 relatively high numbers were found at the eastern end of the line in April and early June.

On the Bremen (Plates LXXXV and LXXXVI), as on the Rotterdam line, Acartia showed a summer maximum. June, 1932, July, 1933, May, June and July, 1934, April, May, June and July, 1935, May to July, 1936, and May, 1937, were the months when the genus was most successful. High numbers were taken at the eastern end of the line in October and November, 1932, after two months of scarcity, and after a depletion in December another increase was observed in this position in January and February, 1933. As stated above, this was the outstanding winter for the other Copepoda, but whereas they were again relatively abundant in the following winter, this proved to be a particularly poor period for Acartia.

It is interesting to note the frequent occurrence of coastal patches. These may be due to the predominance of *Acartia longiremis*, which is reported to be essentially a neretic form flourishing in low salinity water. It is hoped that in the future there will be time available to make a specific analysis of the denser patches of Acartia already recorded with a view to determining this.

Acartia appears to have been scarce in the more Northern parts of the area during the years under review, Plates LXXXVII and LXXXVIII. The only dense patch on the Copenhagen line was found off the north-eastern end of the Dogger Bank in July, 1936. In the two very successful copepod summers, 1935 and 1937, Acartia was relatively well represented on the Bremen line and Esbjerg line (see Plate XCIII), but on the Copenhagen line it appeared no more abundant than in the other years. There is, however, in each year some indication of a numerical superiority of the summer population over the winter.

THE DISTRIBUTION OF *Centropages typicus* AND *Centropages hamatus.*

In 1933 *C. typicus*, Plate LXXXIX, was first identified on the Rotterdam line in late July, towards the eastern end. It persisted here until January, 1934, being very abundant near the coast in October and December, 1933, and January, 1934, but never extending to the western half of the line.

In comparison with that of 1933–34 the winter of 1934–35 showed a very low *C. typicus* population. The species was present in the centre of the line in September and occurred in low numbers in the east in November and December. It was also recorded as present in the west near the Dudgeon light-vessel in November, and it is an interesting point that this is the only occasion on which the species was taken at this end of the line.

The only occurrence in 1935 was in June on the eastern half of the line, as the 1935–36 winter population failed to appear.

Moderate numbers were taken in the autumn of 1936. In 1936 the highest numbers appeared to be near the Dutch coast, but in 1937 the centre of concentration was further offshore. In 1937 the species disappeared earlier than usual, being recorded only as present in November and not at all in December.

On the Bremen line, Plate XC, *C. typicus* was again usually found on the winter records, appearing in August or September and at times persisting until March.

In 1932 the species was well represented. It first appeared in September, stretching well across the western half of the line, but centred in a patch about 60 miles from the English coast. The October record was short in the west, but it showed a high concentration to the east of the patch found in the previous month and a few individuals in the extreme east. The November record revealed a similar concentration, and also that the species extended well towards the English coast in the region not sampled by the October record. By December the species had decreased considerably, only low numbers remaining near the centre.

In the winter of 1933–34 *C. typicus*, although never occurring in numbers as large as those found in 1932, was both widespread and persistent. It first occurred in low numbers on the western half of the line in August, increased in the west in September and spread across the line in October and November. Unfortunately the December record was short on the English side, but there were still a number on the eastern half of the line and indications of it persisting in the west. By January, 1934, the species was restricted to a patch in the east, just west of the Borkum Reef, and a similarly placed patch was found in March. In February and March a few individuals were also found near the centre of the line.

The winter of 1934–35 showed a distribution very similar to the previous one, but the numbers were much lower ; the species was recorded as present in the west in September, spreading eastward in October and November to an easterly preponderance in December. In January, 1935, it was again recorded as present in a position corresponding to the patch found in the January of the previous year and also in the centre of the line in March.

As on the Rotterdam line, the 1935–36 population was even poorer than that of 1934–35. The species was present on the September record to the east of the centre, and in October, November and December occurred spasmodically across the line. In spite of the low numbers there was indications of the west to east restriction during this period.

In the winters of 1936–37 and 1937–38 *C. typicus* had a more easterly distribution. In both these seasons there was a concentration towards the eastern end of the line in September, October and November. In both years it first appeared in August, in the centre in 1936 and in the east in 1937. There were also other records of its presence in the area during these periods, but it was never in appreciable numbers. In October and November, 1937, when the line was extended to the Norderney Light-vessel, the species was found to extend to the end of the line, and in November there was a relatively high concentration outside the area normally sampled. It is probable, in view of this, that in 1933 and 1936 when the numbers were still increasing at the point where the Recorder was hauled, considerably denser populations would have been found had the record been continued.

The distribution of *C. typicus* on the Copenhagen line (Plate XCI) differs from that on the two southern lines in one striking respect. Whereas, as has been already pointed out, there is a spatial sequence or restriction on the latter, this is not apparent on the former. The distribution in fact although generally low is surprisingly even. The species occurred along the line during the second half of each year, and persisted until January in 1933, 1934, and 1937. It is difficult to pick out any year as either successful or unsuccessful for the species here. It is interesting to note, however, that the population may establish itself earlier on this line than on the others, for example, in August, 1934, 1936, and 1937, and July, 1935.

By reference to Plate LXXXIX it will be seen that on the Rotterdam line *Centropages hamatus* is essentially a summer form, though it may occur at any time in the year. In each summer the maximum was reached in July.

In 1933 it was taken from January until September, and the late July record of this year showed the densest population found on this line during the survey. 1934 was a poorer season; the species was taken only in April, July, August and September, and then in low numbers. 1935, although no numbers were found as high as those in July, 1933, was probably the most successful season for this species. It was present on the January record, from July to September extended across the line and persisted into October and December. In 1936 it was again taken in fair numbers in June and July, and from then on was recorded as present on various parts of the line until December. It reappeared in the eastern winter population in February and March, 1937, and subsequently showed the usual midsummer maximum in June, July and August, and was taken again in October.

On the Bremen line (Plate XC) the distribution of *C. hamatus* followed that on the Rotterdam line fairly closely, though here the maximum was reached slightly earlier, the richest month being May or June, rather than June or July. It is interesting to note that the three years in which it was taken in January and February, 1933, 1935, and 1937, coincide with the years of early occurrence on the Rotterdam line. Here, again, it was a regular member of the plankton during the midsummer months and occurred spasmodically in every other month excepting December. The summer population was in every year more abundant on this than on the Rotterdam line.

C. hamatus on the Copenhagen line (Plate XCI) again showed a well-defined summer maximum. The shortage of data makes it difficult to define within narrow limits the months of occurrence, but it is clear that it had a more successful if shorter season here than on the two more southerly routes, and that it reached its maxima slightly earlier in the year. It was abundant in July, 1933, May, 1935, June, 1936, May and June, 1937, and the only month in which it was found in 1934 was April. On the other hand, it was never recorded from the 15 records analysed between August and the end of the year. The appearance of a few specimens in January and February, 1936, is rather surprising, as this was one of the two years in which the species was not found in the early months of the year on the other two lines.

On the series of Plates CVII–CXVIII the two species of Centropages have been combined on a set of monthly maps. These serve to make clearer the distribution of the genus in the area, and at the same time show the exclusion between the species. This is thought to be important for reasons that will be explained later, but it may be pointed out here that it seems probable that these two species will prove to be valuable indicators.

As will be seen, there was only data for the Bremen line in 1932. In June, July, and to a lesser degree in August there was a relatively successful *C. hamatus* population centred about the middle of the line. This gave place in September to an equally successful *C. typicus* stock which persisted in October and November to decrease sharply in December. By January, 1933, it was no longer present in the Bremen line, though a few individuals were taken on the Copenhagen line over the Dogger Bank. We find, however, a certain amount of *C. hamatus* from January until April on the eastern ends of the Bremen and Rotterdam lines, forming a part of the coastal concentration of copepods typical of the winter, and it may be remembered that for the total copepod population this was a particularly successful winter in this region. There was an unfortunate shortage of records in May and June, but we can see that *C. hamatus* had become fairly common on the Bremen line in the former month and that by July it was found all over the area sampled. In August, September and November low numbers were recorded on the Rotterdam and Bremen lines. This autumn was marked by the outstanding success of *C. typicus*. Appearing as a few individuals as early as July, it increased to cover the whole area by October or November and persisted until the following March. It played a very important part in the winter coastal population, probably being the dominant species off the Dutch coast in December and January—a remarkable change from the previous January when it was not found there at all. In April, 1934, *C. hamatus* reappeared, and although not very abundant, spread well across the Bremen line in May, June and July. By August *C. typicus* was again present on the Copenhagen line and proceeded to replace *C. hamatus*, although the latter cropped up here and there until November. *C. typicus*, although widespread, was not this autumn nearly so successful numerically as in the previous one. In fact, except for two traces on the Bremen line in January and March it did not appear in the early months of 1935. The spring and summer of 1935 again found *C. hamatus* successful, especially in the centre of the area, and giving way in the autumn (October, November, and December) to a fairly sparse *C. typicus* stock. It is important to note for subsequent comparison with other species that this year *C. typicus* apparently failed to establish itself in the southern part of the area. Although it was well represented on the Copenhagen line in September and October and appeared in lower numbers on the Bremen line, it was only taken on the Rotterdam line in June, whereas *C. hamatus* was found in October and December.

1936 was in many respects similar to 1935. *C. hamatus* was as usual successful in June and July, while *C. typicus* appeared on the Copenhagen line in August and spread southwards. Unlike the previous year, however, it became well established in the winter population off the Dutch coast. Again in 1937 we find *C. hamatus* predominant from May to June. In July there was no Copenhagen record, but small numbers of *C. typicus* were mixed with the *C. hamatus* about the centre of the Esbjerg line. In August it was well established on the Copenhagen line, and subsequently covered the whole area to the exclusion of the other species. As in 1933 and 1936, it became a prominent constituent of the coastal population.

THE DISTRIBUTION OF *Isias clavipes*.

Isias clavipes and the cyclopoid *Corycaeus anglicus* are plotted on a series of maps in Plates CXIX–CXXV. Such an arrangement is convenient for these two species, because by considering the three lines together it is possible to get a better idea of the pronounced seasonal and spatial restrictions which are the striking points of their distribution.

As is explained in the legend preceding Plate CXIX, these species only occurred in appreciable numbers during the later half of the year, and consequently for economy of space the maps representing the earlier part of the year have been omitted. Occasionally odd individuals of Corycaeus were recorded in January, February or March. These were most likely stragglers from the winter stock, and have been indicated by black circles on the December map, except in the case of the winter of 1933–34, when an extra map appeared necessary.

Considering first *Isias clavipes*, it will be seen that although none were found on the Bremen line in June and July of 1932, by August it had appeared in a relatively dense patch at the western end. This patch persisted to a lesser extent in September, but by November had disappeared. The October record was 60 miles short at the English end, but the species was present at its finishing point.

In 1933 Isias was again only recorded in three months, July, August and September. In July there was a patch on the western end of the Bremen line similarly placed to that found in August, 1932, although not so dense. In addition it had appeared at two points on the eastern end of the Rotterdam line. By August there had been an extension to cover the southern part of the area. There was no data for the Copenhagen line, but the species extended well out to the middle of the Bremen line and was present in low numbers over a broad stretch of the eastern half. The western population had extended south to the Rotterdam line, where a high concentration was found off the East Anglian coast and at the same time the numbers on the eastern half of this line had increased. There was a trough of low concentration in the middle of both lines. By the following month, September, there was little change in the western population, but those on the eastern half of the Bremen line had disappeared. Unfortunately there was no information from the eastern half of the Rotterdam line. A few individuals were found over the South-West Patch on the Copenhagen record.

In 1934 the season again lasted from July to September, but the distribution was not at first like that of the previous year. There was in July a fairly rich population in the middle of the Bremen line and a single record of presence on the Rotterdam line about 50 miles from Spurn Point. By August there were indications of a restriction to the region off Spurn, but the numbers were still low and stretched well across the Bremen line. In September, however, there was a marked improvement in the numbers and the well-defined restriction found in September, 1933, had re-established itself. A few records of presence were all that remained of this in October and November.

The appearance and subsequent behaviour of the Isias population in 1935 was very similar to that of the previous summers, but the stock was less successful. In July it was found in the centre of the Copenhagen and Rotterdam lines, and at a point towards the English end of the Bremen line. Through August and September there appeared a progressive restriction to the off-Humber region, which was found in the previous years. This was followed by the usual rapid decline, leaving only a few stragglers on the Bremen line in the following month.

In 1936 Isias was common only in the centre of the area. It never appeared on the Rotterdam line, and not until September was it taken on the Copenhagen line. In June there was a patch on the English side of the Bremen line which increased until it practically covered the line in August. The September records showed a decline on the Bremen line, but the species had widened its distribution sufficiently to cover the major part of the Copenhagen line.

In 1937 the species was first found on the Esbjerg line in July. It was taken at the southern end, where the line is near the Suffolk coast. In August, although it extended well across the Bremen line and was present on the far end of the Rotterdam line and the Dogger Bank, there were indications of the Western preponderance which seems to be the normal distribution at this time of the year. This persisted in September, and in October low numbers were taken across the western half of the Bremen line and on the centre of the Rotterdam line. Numbers were well below normal in 1937.

THE DISTRIBUTION OF *Corycaeus anglicus*. (PLATES CXIX–CXXV.)

Corycaeus anglicus was found to be a winter form, reaching its yearly maximum in November or December.

In 1932 it was well represented at the extreme eastern end of the Bremen line in October and November and was recorded as present here in December.

In 1933 it first appeared in September in low numbers on the western half of the Copenhagen line and on the extreme east of the Bremen line near the Borkum Light-vessel. For the next three months it was relatively abundant near the Dutch coast on the two southern lines and less abundant towards the centre of the area. There was only one Copenhagen line analysed during this period, that for

November, and Corycaeus was present along most of its length. This winter it was particularly persistent. There were four records of its presence in January, 1934, and one in both February and March.

In 1934 the species was again relatively successful, but its distribution differed from that of the previous year. Its centre of concentration was rather nearer the middle of the Bremen line than along the Dutch coast, and from October to December it was present along the whole length of the Bremen line and showed no signs of the restriction to the east found in 1933. Further it was only taken on the Rotterdam line in very low numbers. It appeared earlier, in July on the Bremen line and remained present there until February. It was well established on the Copenhagen line by September. During this year on two occasions it occurred in a patch of Isias on the July and September Bremen records. This rarely happened because usually the two species were separated both in space as well as in time.

1935 saw a very pronounced reduction in the Corycaeus population. It was recorded as present on the Bremen line in August, and in low numbers on the eastern ends of the September Bremen and Copenhagen records. It was scattered over the Bremen line in October, November and December, and present on the far end of the December Rotterdam record. It was later present on the centre of this line in March, 1936.

In 1936 the species had reached a very low level, constituting an insignificant part of the winter copepod population. There was a small patch on the eastern end of the Copenhagen line in September, as in 1935, but apart from this it never occurred in appreciable numbers. It was, however, present on the Bremen line in November and December at the eastern end, and on the Rotterdam line in October and December, and well scattered over the November Esbjerg record.

The following year saw a recovery in the area. Small numbers were taken as early as July on the Esbjerg line, by September the species had established itself on the far half of the Copenhagen line, and moderate numbers were taken there until the end of the year. In October and November high numbers were found in the Heligoland Bight, in fact higher than in 1933 and 1934. At first sight it appears that this period was the most successful for Corycaeus during the survey, but this is improbable in view of the fact that the bulk of them were taken on the extension of the Bremen line not previously sampled, and that the species did not extend so far south as in 1933 or as far west as in 1934. 1935 and 1936 were very lean years when compared with the other three.

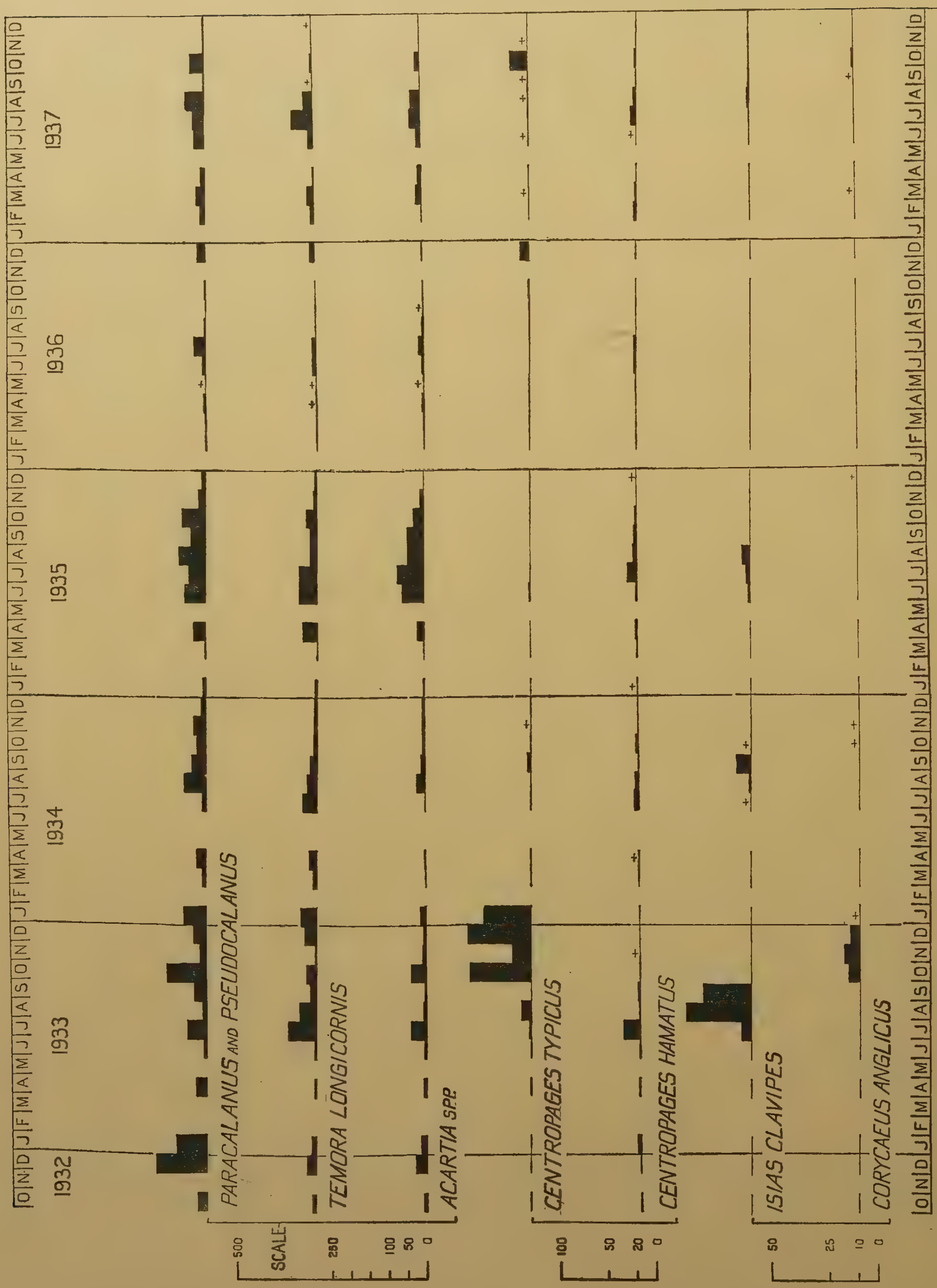
THE SEASONAL VARIATIONS IN THE ABUNDANCE OF THE COMMONER COPEPODA.

In the brief description of the distribution of the various genera and species some remarks have been made about their relative abundance in time. As it is not easy to correlate this information from the distribution graphs alone a pictorial summary has been made in the following manner : The number of individuals of each species caught in any month is totalled and divided by the number of miles sampled in that month. This procedure is followed for each line to give the average number of individuals per mile of tow for every month for which there is information. These figures are arranged as histograms in a chronological series. The various species are placed beneath each other for the three lines in turn (see Text-figs. 6, 7 and 8).

There are a number of points to be borne in mind when considering these diagrams, as false impressions can be made if they are treated too literally. For example, if a species has a very restricted spatial distribution, a single patch on the Copenhagen line will, on account of the relatively greater length of tow, give a far lower average value than a patch of similar dimensions found on the Rotterdam line. A similar situation arises when a record is considerably shorter than usual owing to a mechanical defect or to weather conditions. In such circumstances the mean value may be unfairly high or low according to whether the part sampled was one of higher or lower density than the part that was not. For this reason only those records that are valid for more than half their length have been used, but nevertheless it must be remembered that on some of the winter Rotterdam records practically all the copepods found were taken on quite a small fraction of the total length. Another point is that as the records could not be evenly spaced in time, on some occasions a sample taken in the first or last few days of a month has had to be used to give a value for the whole of the month. In spite of these limitations, which will only effect isolated cases, there are a number of trends which appear more clearly in this summarized arrangement of the data than in the distribution graphs.

Considering first the Rotterdam line (Text-fig. 6) it will be seen that the three main genera, Pseudocalanus (+ Paracalanus), Temora and Acartia did not vary much in abundance from year to year. The outstanding points are the weakness of the 1936 population for all three, and the surprisingly dense population of Pseudocalanus in December, 1932, and January, 1933. On the whole, 1933 and 1935 appeared to be the most successful years, though 1935 was more markedly so for Acartia than the other two genera.

Turning to the Bremen line (Text-fig. 7) it will be found that Pseudocalanus was far more abundant than on the Rotterdam line, even the least successful year, 1933, being comparable to the more productive years on the Rotterdam line. It is interesting to note, however, that the difference is more pronounced during the summer months of maxima than during the winter, or that there was a more even and stable population throughout the year on the southerly route. The outstanding year for this group was 1935. In this year the average for the maximum month, May, was approximately twice that of the maximum month of any other year, and further the averages for April, July and August were also in excess of the usual maxima. 1934 and 1936 were both comparatively successful years, and the autumn population of 1932 was, as on the Rotterdam line, surprisingly high.



TEXT-FIG. 6.—Histograms showing the average number of the commoner Copepoda caught per mile of tow on the Rotterdam line for each month from October, 1932, to December, 1937. The values represent the total catch per month divided by the distance sampled. Records of less than half their normal length are discarded, and months in which there is no valid average are indicated by a break in the base line. A " + " sign denotes that the form was present, but in numbers too small to be shown on the scale adopted. For further explanation see text.

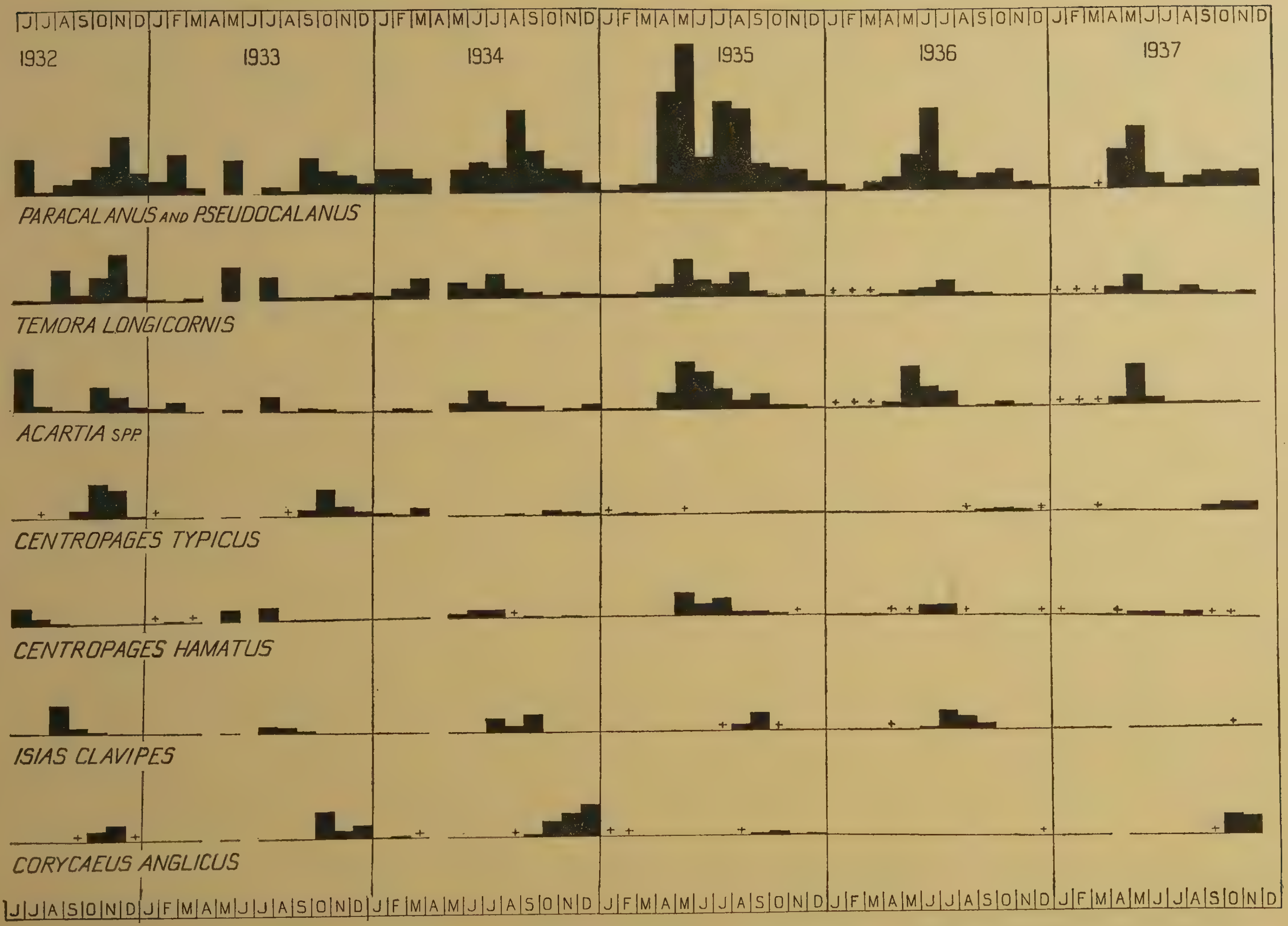
The numbers of Temora and Acartia taken were more comparable with those on the Rotterdam line, 1936 and 1937 being weak years for the former and 1933 and 1934 for the latter. The summer of 1935 and autumn of 1932 were the most successful periods.

The Copenhagen data (Text-fig. 8) are far less definite. There is a possibility of the maximum for a year occurring in a month not analysed and a false impression so being obtained. It is clear, however, that Pseudocalanus was very well represented on this line. From 1933–35 there was a steady increase in numbers, followed by a decrease in 1936. Whereas on the Bremen line in 1937 the lower numbers were maintained, in June, 1937, on this line the highest mean value of the survey was found. Of the other two genera one can conclude that either they had a far shorter season or else they were on the whole lower than on the Bremen line. The high concentration of Temora in June, 1935, is an exception to this generalization.

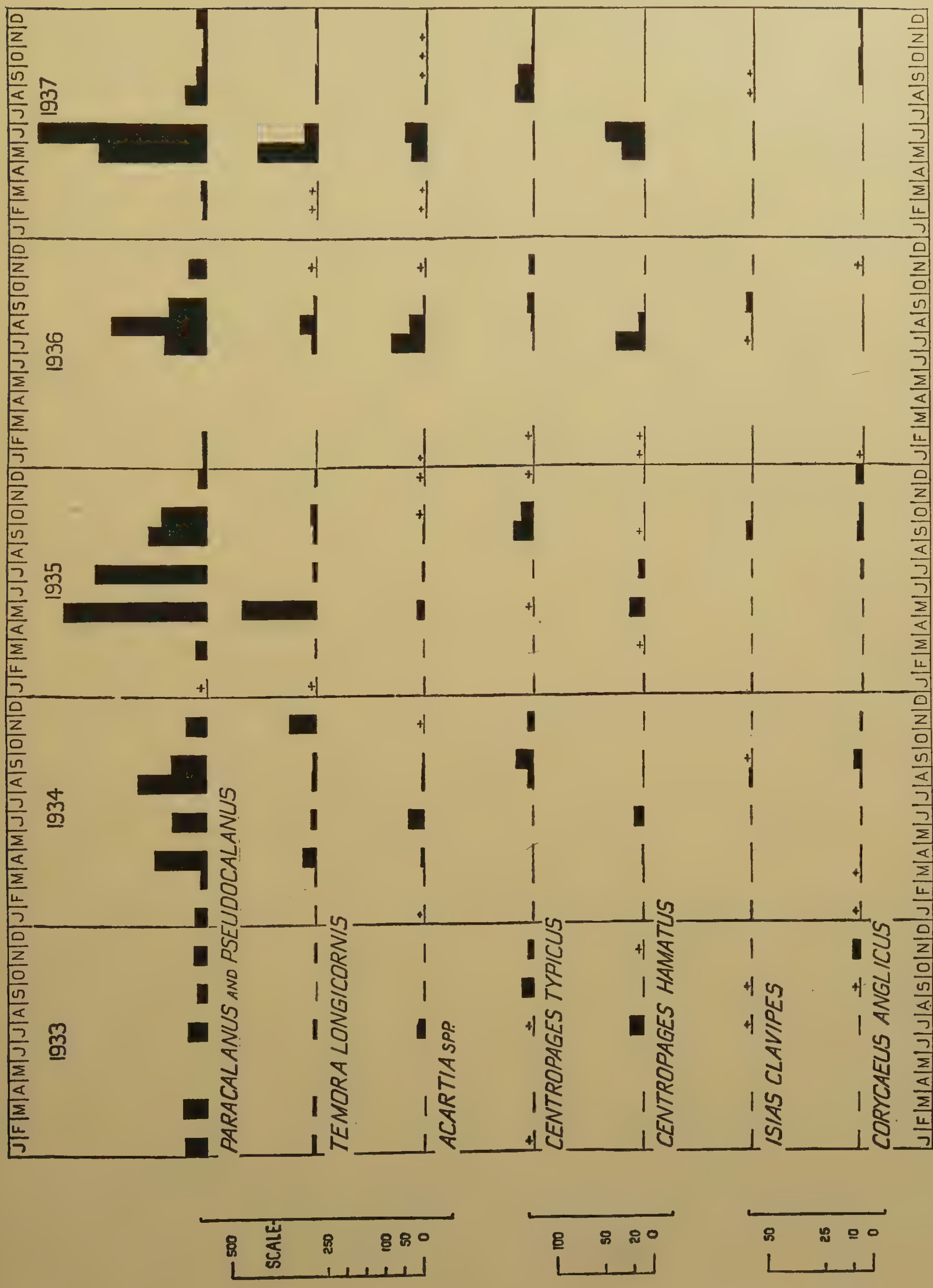
By far the majority of the Copepods taken during the survey belonged to the three genera, Pseudocalanus, Temora and Acartia. These are in Text-figs. 6, 7 and 8, plotted at $\frac{2}{5}$ of the scale used for the two species of Centropages and $\frac{1}{5}$ of that used for Isias and Corycaeus. It will be seen that they were present on practically every roll analysed. Centropages, Isias, and Corycaeus, on the other hand, appeared to have a far more marked periodicity, occurring annually only over a comparatively short season. Such a seasonal variation might be due to two distinct causes. Firstly these might be species that normally flourished in an area not sampled by the survey and carried on to the lines at certain times only, or they might have normally occurred in such numbers that they were only taken by the recorder or revealed by the process of analysis during those months in which they reached their maxima. The relative merits of these two possibilities will be discussed later (p. 233); at the moment it is sufficient to draw attention to the more striking points regarding their occurrence on the lines.

Centropages typicus and *Corycaeus anglicus* were winter forms, as has been pointed out above. They first appeared in appreciable numbers about September and persisted until the early months of the following year. These species showed similar fluctuations in their abundance as well as an agreement in the times of their occurrences. 1933 was by far the most successful year for both species on the Rotterdam line, and in the winter when *C. typicus* persisted into the following year, it was found that Corycaeus did the same. It will be seen that both were poorly represented on all three lines during the winter of 1936, and show a slight improvement in the following winter. It is interesting that neither species enjoyed the advantages that the conditions of 1935 appeared to give to the more common species.

Centropages hamatus and *Isias clavipes* were summer species. Considering *C. hamatus* first, it will be seen that it showed very little variation. It occurred every mid-summer on all three lines. The variations from year to year were slight, 1935 being the most successful year on the Bremen line, 1936 and 1937 on the Copenhagen line and 1933 on the Rotterdam line.



TEXT-FIG. 7.—Histograms showing the average number of the commoner Copepoda caught per mile tow on the Bremen line for each month from June, 1932, to November, 1937. General arrangement as in Text-fig. 6.



TEXT-FIG. 8.—Histograms showing the average number of the commoner Copepoda caught per mile tow on the Copenhagen line from January, 1933, to December, 1937. General arrangement as in Text-fig. 6.

Isias clavipes never showed a high average value on the Copenhagen line. This doubtless is in part due to the very marked restriction of the species to a region off the Humber mouth and the relatively short part of the Copenhagen line which samples this area. On the Bremen line its value remained fairly constant for the few months in which it occurred each year with the exception of 1937, when it hardly occurred at all on any of the lines. This is in contrast to the findings on the Rotterdam line, as there was there a very dense population in August and September, 1933 ; in 1936 the species was not taken at all on that line.

The seven groups of copepods dealt with above, although varying in their normal abundance, are the main constituents of the population in the area covered by the survey, and for the purpose of this report must be considered as the most important. *Calanus finmarchicus* is to be the subject of a special report (see p. 204), but neglecting for a time this species, there can be little doubt that the Pseudocalanus-Paracalanus, Acartia and Temora groups together must form the significant link in the food chain, simply because of their numerical superiority over the other copepod forms (see also p. 195). The species of Centropages, Isias and Corycaeus have been considered in some detail, because it is thought that their particular types of distribution both in space and time make them useful in the study of water movements and changes in the physical conditions of the environment which is an immediate objective of the investigations.

As was pointed out in the introductory section a number of other species were taken and identified. Although space would not permit any detailed consideration of their distribution even if they were ever present in numbers sufficiently high to warrant it, it is felt that some summarized account of their occurrence is valuable in an understanding of the ecology of the area. In order to do this as briefly as possible it has been necessary to adopt different methods of presentation at the expense of consistency.

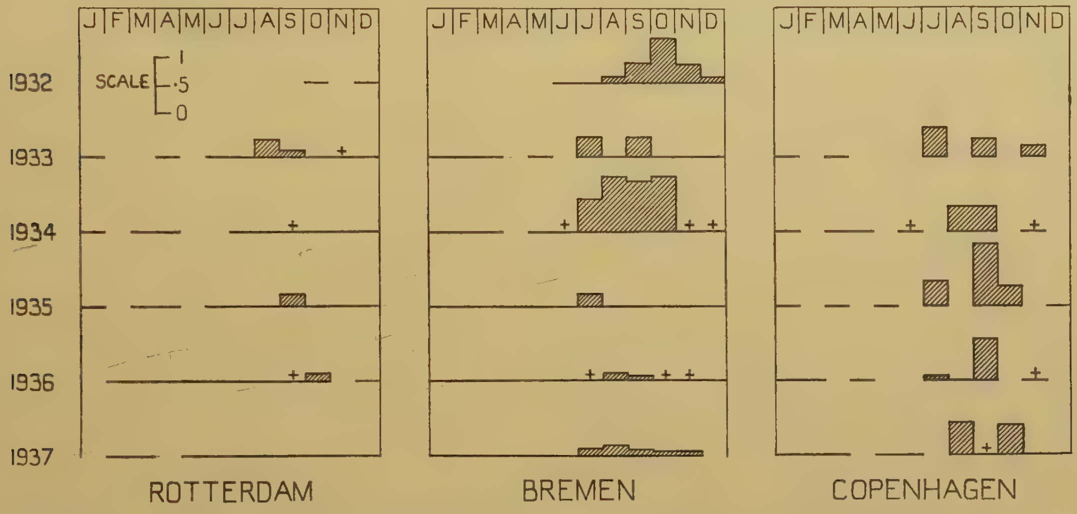
The Occurrence of Other Species of Copepoda.

(1) *Labidocera wollastoni.*

Labidocera wollastoni was never abundant when compared with the smaller copepoda. It was taken in ones and twos when the commoner species appeared in hundreds, but nevertheless occurred with regularity during certain months each year. This is illustrated in Text-fig. 9, where its monthly averages are presented. The average number caught per ten miles of tow in each month is estimated ; after adjustment for the size of aperture, these are plotted as histograms, one for each line in each year.

It will be seen that Labidocera was not so well represented on the Rotterdam line as on the other two. Not only were the average numbers lower, but the period of occurrence was shorter. In 1933 the species was taken in August, September and November, and the figures estimated for the former two months show this to be its most successful year on this line, whereas 1934 and 1937 were the poorest.

On the Bremen line the species was generally more persistent. It will be noticed that in four years out of the six, it was present for five or six successive months. 1933 and 1935 were the years in which the season was shorter, while 1932 and 1934 were particularly successful. In 1936 and 1937, however, although the species was found for periods of five months, it was never present in high numbers. The normal period of occurrence on this line seems to be the summer and autumn.



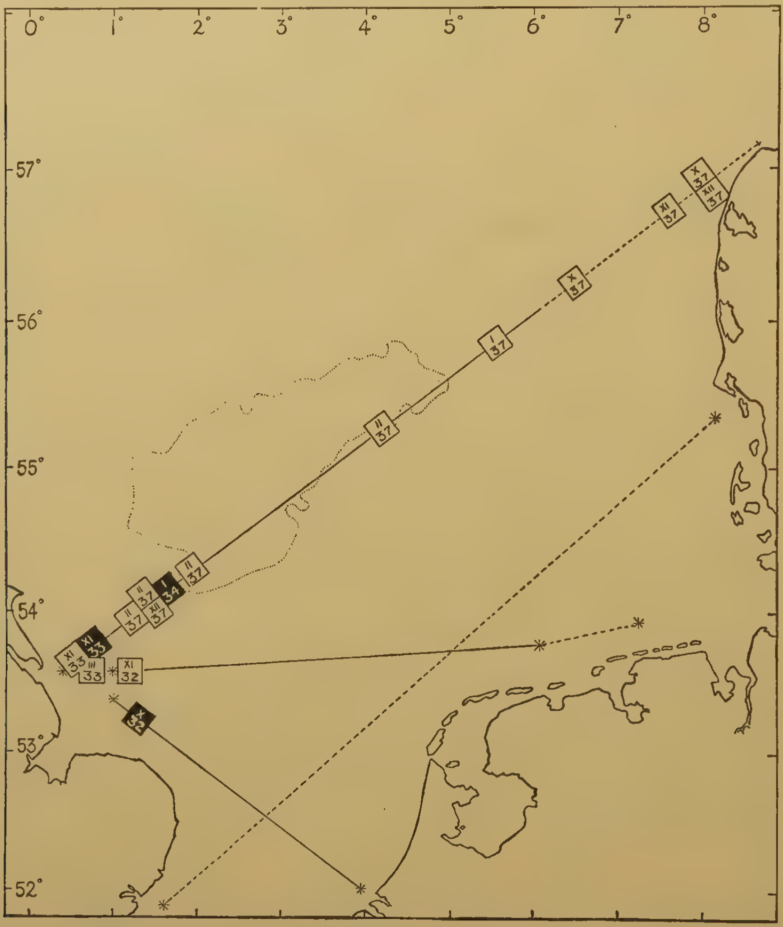
TEXT-FIG. 9.—Histograms showing the monthly fluctuations in the average number of *Labidocera wollastoni* caught per mile on the Rotterdam, Bremen and Copenhagen lines from 1932 to 1937. A break in the base line indicates that data were not available for at least half the usual mileage sampled. A " + " sign denotes that the species was present, but in numbers too small to be shown on the scale adopted.

The Copenhagen line was quite as productive as the Bremen, and here the species was taken over the same season. It is not easy to compare the years for the relative success of the population because a different series of months was sampled in different years, but judging by the September record it appears that 1935 was above the average, and that there was very little difference between the other years. This is rather unexpected because in 1935 as stated above the species hardly established itself on the Bremen line at all.

No diagrams are included in this report showing the spatial distribution of Labidocera. It was usually found at scattered points over the centre part of the lines, but might in its more successful months cover practically the whole area. As will be seen from the monthly histograms it was always more abundant in the more northerly records.

(2) *Anomalocera patersoni.*

This species was practically absent from the Recorder material, two isolated records of presence being the only indication of its occurrence in the area during the period of the survey (see p. 230).



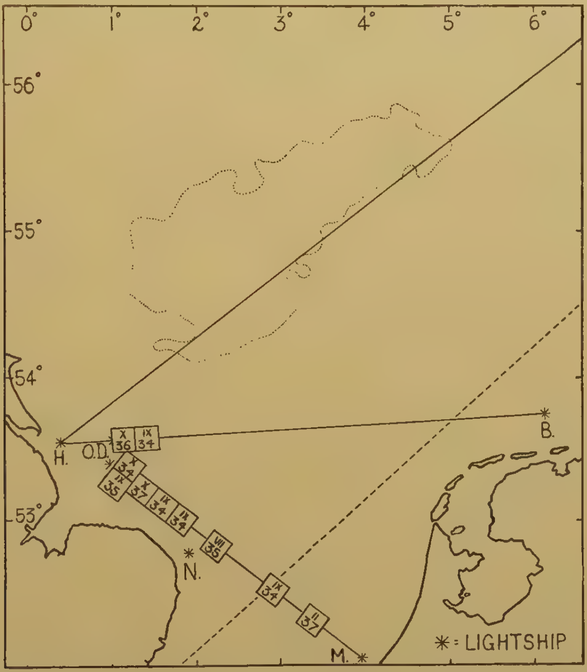
TEXT-FIG. 10.—A chart showing the occurrence of *Metridia lucens* (open squares) and *Candacia armata* (black squares) on the recorder lines from 1932 to 1937. The month and year of each occurrence are indicated by numerals in the squares. The broken lines represent additions to the survey only sampled during the latter half of 1937.

(3) *Metridia lucens.*

Metridia lucens was recorded as present on 13 occasions only. These are arranged on a map in Text-fig. 10. It will be seen that they all fall in the winter months, between October and March. In November, 1932, and March, 1933, the species was found on the Bremen line in the vicinity of the Dowsing and Humber Light-vessels. It reappeared in November, 1933, in a similar position near the Humber Light-vessel, but was not taken again until the beginning of 1937. 1937 was in comparison with the others a good year, as the species was present at ten stations. In the early part of the year it was taken at a point north-east of the Dogger Bank in January, and in February at three stations around the south-western end of the Bank and at one over the northern part. In December, 1937, the species was again found in the same place as the February observations, off the South-West Patch. From October to December, 1937, it was also found on the extension of the Copenhagen line, but there is, of course, no comparable data for this region in the earlier years.

(4) *Candacia armata.*

Candacia armata was very rare, only being taken on three occasions—October, 1932, November, 1933, and January, 1934. Each of these records fell in the western part of the area, on the Copenhagen line between the Humber Light-vessel and the Dogger Bank and about 20 miles south-east of the Dudgeon Light-vessel (see Text-fig. 10).



Text-fig. 11.—A chart showing the occurrence of *Parapontella brevicornis* on the recorder lines from 1932 to 1937. Arrangement as in Text-fig. 10.

(5) *Parapontella brevicornis.*

Parapontella brevicornis was not found until 1934, when it was taken five times. It appeared twice in 1935 and 1937, and only once in 1936. The bulk of the observations come from the Rotterdam line (see Text-fig. 11).

(6) Oithona spp.

Any treatment of this genus has been abandoned for the reasons given on p. 198.

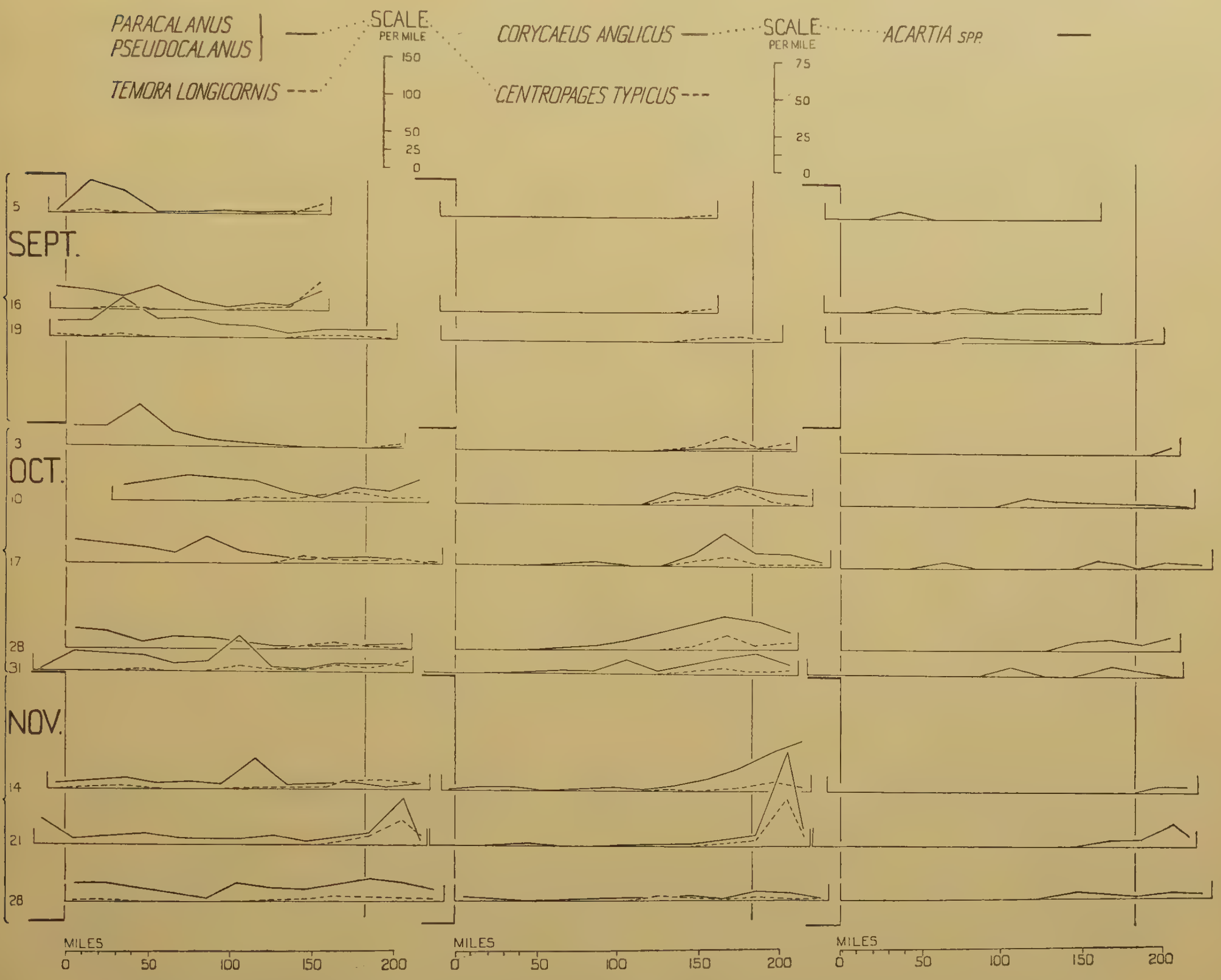
THE AUTUMN PROGRAMME, 1937.

In each year, during September, October and November, the usual monthly records were augmented by a weekly series on the Bremen line whenever the sailing dates and weather conditions permitted. The object of this was primarily to afford additional information about the extent and movements of the main autumn diatom patches, which have been shown under certain circumstances to control the movements of the herring and so affect the main fishing season (Savage and Hardy, 1935). As there was not sufficient time available to analyse even a complete monthly series of records for the individual copepod species, there seemed little point in dealing with these extra rolls, especially as they were taken at a time when the population was generally low, and also when the herring were not feeding in the area. Nevertheless it was realized that a weekly series would be valuable for giving some idea of the rate at which the copepod population might change at any one point, and the practicability of interpolation between the usual monthly observations. Further, such a series might, by the consistent appearance of any particular distribution over a number of records, give an added amount of confidence in the method.

For these reasons it was decided to analyse one autumn series fully. September, October and November, 1937, were selected because there was then a fairly comprehensive programme completed, and because during this period the bulk of the copepods had apparently moved from the western end of the line to the eastern end.

The results from these records are not all included in the annual diagrams for the various species, because they would there only cause a degree of congestion which would obscure the general distribution. They are presented independently in Text-fig. 12, where the vertical time scale is increased by three times. Only the Pseudocalanus-Paracalanus group, Acartia spp., *Temora longicornis*, *Centropages typicus* and *Corycaeus anglicus* occurred in appreciable numbers on these rolls. Acartia and Corycaeus are plotted at twice the scale used for the other three forms, and consequently appear in this diagram to be more dominant members of the copepod population than they really were.

There is a mile scale placed below each column of graphs, showing the distances from the Outer Dowsing Light-vessel, which is represented by a vertical line at 0 miles, to the Borkum Light-vessel, which is similarly marked at 182 miles. By comparing the general contours of the graphs with these scales, it will be seen that points are only plotted at 20-mile intervals and may fall either on the 15, 35, 55, 75 . . . or the 5, 25, 45, 65 . . . mile series from Outer Dowsing Light-vessel. This is due to the arbitrary selection of blocks for analysis on the basis of taking the first complete block and every other one thereafter until the end of the record. On account of this it is impossible in many cases to find an agreement closer than 10 miles for either the centre or the end of a patch. This point can be illustrated by reference to the western limit of the *Centropages typicus* patch throughout the series. On all three September records the even blocks were analysed giving data for 10–12, 30–40, 50–60 . . . miles east of the Outer Dowsing Light-vessel, and



TEXT-FIG. 12.—Graphs showing the distributions of the commoner copepods found along the Bremen line during the intensive autumn programme of 1937. The vertical lines on the left and right of each series mark the positions of the Outer Dowsing and Borkum light-vessels respectively. They also represent a time scale from September to November on which each graph is placed against its appropriate date (indicated at the left-hand side). Acartia spp. and *Corycaeus anglicus* are plotted at twice the scale used for the other forms. For further explanation see text, p. 224.

in each case the species was present on block 16 (*i.e.* between 150–160 miles east of the light-vessel), and was not taken on block 14 (*i. e.* 130–140 miles east of the light-vessel). For the first record in October, however, the odd blocks were analysed, and then the species was present on block 15 and absent on 13, so that there appears in the diagram a westward extension of the patch amounting to 10 miles, whereas in point of fact the agreement between the two records is as close as the method will allow.

The persistence of this *Centropages typicus* distribution is one of the most striking points in the series. Its western limit is surprisingly constant, as there is no significant movement of this boundary in the eight records for September and October, and very little if any in November. Quite apart from its biological interest this point is important, because it does reveal the capability of the Recorder method to show an agreement through sequences of observations even when the numbers concerned are low.

There are further points in these records which lend confidence to the method. It will be seen that there are a number of trends running through the series, so that each record appears as a reasonable mean of those preceding and succeeding it. For example, *Corycaeus anglicus* was first taken in very low numbers on the eastern end of the first record in October, had increased by the following week, and then appeared to spread progressively further westward in the next four records, until it extended to the English coast during the second week of November. *Temora longicornis* was found on the eastern half of all the records and also at the western end in September and November, though it was absent there during four successive October records. The distribution of the Paracalanus-Pseudocalanus group also shows a strikingly regular pattern. If the higher numbers are considered, it will be seen that at the beginning of the programme they were situated off the English coast and then moved offshore towards the centre of the line until November, when the highest concentration was found on the eastern side. The actual number of individuals present in this patch, which apparently moved from west to east, is so similar that one is tempted to consider it as a single concentration drifting along the line. Whether this is so or not, one is presented with an anomalous situation in the apparent movements of the various species during these three months. The Centropages population appears to remain stationary, while the Corycaeus population, which at first is conterminous with it, spreads westward against the direction of Pseudocalanus, which steadily moves from west to east. No discussion of the significance or explanation of this will be offered here. The matter will be considered fully and compared with the contemporary data for the phytoplankton in the report dealing with the relationship of the plankton to hydrology in the near future. This series is presented at the moment merely to show that had only one record per month been analysed during this period it would have given a very fair picture of the distribution which has been shown by the weekly records, and to show that the changes in the distribution are gradual ones. It does, however, at the same time go a long way towards convincing one that the errors entailed in the subsampling technique are not nearly as serious as might at first be expected.

A Comparison between the Recorder Results and the International Council's Survey, 1902–1908.

It is thought that at this stage a broad comparison between the findings of the International Council, 1902–08, and the Recorder data, 1932–37, will be of value. For this purpose the summaries of the species listed in the 'Bulletin Trimestriel '[1] will be used, and it is hoped that a more detailed comparison may be made using the figures in the 'Bulletin Planktonique' when later papers dealing with the ecology and life histories of the various species are published. Before this is undertaken, however, as has been pointed out earlier, it is wiser to wait until more information has been obtained from the extended area.

The area defined as "Southern North Sea" by the International Council[2] is practically speaking that sampled by the three Recorder lines in the first five and a half years of the survey. It extends from the mouth of the Channel (South Foreland–Cape Grisnez) in the south to the 60-metre contour in the north. The northern boundary may be considered as a line passing from about Flamborough just north of the Dogger Bank to a point in the mouth of the Skagerrak mid-way between Hanstholm and the Naze lights; this boundary is, in fact, nor far removed from the path taken by the Copenhagen line.

In the 'Bulletin Trimestriel' *Paracalanus parvus* was described as a neritic euryhaline species with a fairly high temperature optimum. It was, from 1902–1908, most abundant in the Channel and Southern North Sea, but there, as in adjacent areas, it was less successful in February and May than in August and November, though in the region off the Belgian coast this was not always so. The species should then be expected to be most abundant in the mouth of the English Channel, extreme south of the North Sea and the mouth of the Skagerrak in the autumn. *Pseudocalanus elongatus*, on the other hand, was considered to tolerate a very wide range of conditions. It was described as being "always present but usually scarce" in the North Sea south of 55° N.; the exception to this generalization being that in the extreme south of the area, the Dover Straits and off the coast of Belgium, it was often abundant. These periods of abundance appear to have occurred most frequently in the May quarter.

If these conclusions are combined to give a picture of the distribution of two species together, we may expect to find in the Southern North Sea a sparse population throughout the year except in a coastal strip of water stretching from the Dover Straits along the Belgian coast, where there may be relatively high concentrations of Pseudocalanus in the spring or summer and of Paracalanus in the autumn. In fact, if the period covered by the Recorder Survey was generally similar in physical conditions to these earlier years, we should find high numbers on the eastern end of the Rotterdam line throughout the bulk of the year, and a relatively sparse distribution over the remainder of the lines. This, however, is very far from being the case. Throughout the survey the Pseudocalanus-Paracalanus group was found to be the predominant element in the copepod population. Further, one of the most striking points revealed was, as mentioned above, the relative success of the group on the Copenhagen and Bremen lines, when compared with that on the Rotterdam line. The pronounced numerical superiority of the "total Copepoda" during the summers of 1934–37 on the more northerly lines was almost entirely due to these species, which frequently constituted more than half of the entire catch. This is well illustrated in the monthly average histograms in Text-figs. 7 and 8. Although no accurate data is available for the relative proportions of Pseudocalanus and Paracalanus, there is no doubt that the former was by far the more common. Fairly large numbers of Paracalanus were found during the winters off the Dutch coast, but at no other time did it approach the density of Pseudocalanus.

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[1] Farran (1910 and 1911), pp. 60–105, and Scott (1911), pp. 106–149.

[2] See Kyle (1910), p. viii.

It is very difficult to assess the criteria used for "common" and "scarce" in the 'Bulletin Trimestriel,' as the commonest species in the Southern North Sea might well be scarce when compared with its concentration in more productive regions, such as the Skagerrak. As all the Recorder material was taken from a comparatively restricted area, there is no opportunity of testing this, but nevertheless it is clear that during the period 1932–37 the copepod population was very different in constitution to that studied from 1902–08. A comparison between the International Council's findings and the Recorder results shows an important difference: in the earlier years Pseudocalanus was little, if at all, more successful than the other common species. It appears that the high concentrations of Pseudocalanus which were found by the Recorder in the Dogger Bank region in the summer months failed to establish themselves between 1902 and 1908. The significance of this change of distribution will be considered in relation to the broad changes in hydrological conditions in a paper dealing with water movements which is now being prepared. There is, however, a general agreement between the periods of maxima for the two species; Pseudocalanus in early summer, and Paracalanus in late summer or autumn.

Farran (1910) described *Temora longicornis* as a neritic species capable of surviving a wide range of physical and chemical conditions. He commented on the fact that it was absent from the Atlantic current and scarce on the shores which were directly under its influence. This species, like *Pseudocalanus elongatus*, was usually present throughout the year, but only in small numbers in the extreme south of the area, *i. e.* between the Norfolk coast and the Hague, and seemed to thrive more successfully in the channel than in the Southern North Sea. Here again the Recorder results are only in part agreement with his findings. It is true that a relatively higher proportion of the copepod population on the Rotterdam line was made up of Temora, but this was not due to a greater success of the species in the south, but due to the comparative weakness of the Pseudocalanus-Paracalanus group. In fact numerically the species was fairly evenly spread over the

Southern North Sea, and its variation from year to year was small in comparison with some species. The reason that this species did not share the successful summer periods on the Copenhagen and Bremen lines to the same degree as Pseudocalanus might have been in part due to its absence from inflowing Atlantic water. Such a possibility will be discussed more fully at a later date.

The group identified on the Recorder rolls as Acartia spp. is comprised almost entirely of the two species *Acartia clausi* and *Acartia longiremis*, the latter being definitely predominant. These two species are markedly different ecologically. The former is described as oceanic, being most common in the area affected by the inflowing high salinity water in the Straits of Dover and round the Shetlands, whereas the latter is strictly neritic, thriving in the mouth of the Skagerrak and off the Norwegian coast in the region of dilution by the Baltic effluent. In view of this it seems doubtful if a comparison between the two sets of observations has any value.

Scott (1911) found *Centropages hamatus* to be one of the more common calanoids in the North Sea from 1902–08. He decided that although it was a truly pelagic form, it was more abundant in coastal or restricted waters than in open sea. The ‘ Bulletin Trimestriel ’ showed that it was rare in winter, reached a maximum in May, persisted as common during the August quarter, and then declined. Giesbrecht (1882) described it as being frequent in the first part of the year and then rarer. The Recorder data fully confirm such a seasonal distribution. It was usually present on all the lines during the mid-summer months, reaching its maximum in June or July, and was rarely taken during the winter. It was, however, far less abundant than Pseudocalanus, Temora and Acartia spp.

The ‘ Bulletin Trimestriel ’ on *Centropages typicus* is interesting when compared with our present data. It was considered as an oceanic species and was only common in areas of Atlantic influence, such as the western part of the Channel and the Faroe-Shetland region, while it was only sparingly distributed over the central and Southern North Sea. It appeared to have a maximum in August or November. On all three Recorder lines in each year there were indications of a maximum towards the end of the year, usually in September or October. It may be remembered that it was usually during this period scattered fairly evenly along the Copenhagen line, but was restricted to the eastern ends of the Bremen and Rotterdam lines, and it was here in the Dutch coastal waters and the Heligoland Bight that the species was most successful. This area is well within the influence of the tongue of high salinity water flowing through the channel, and in view of the species’ relative abundance in the channel and its high salinity optima, one might expect some agreement between the strength of inflow through the Straits of Dover and its concentration. Strangely the reverse seems to be the case. The most successful winters for the species were 1932 and 1933, which were years of comparatively weak flow of water past the Varne Light-vessel (see Carruthers, 1935). This is an apparent anomaly which requires further consideration. It will be dealt with when detailed figures for the changes of salinity in the area are available.

Unfortunately the 'Bulletin Trimestriel' contains no summary of the distribution of *Corycaeus anglicus,* which we have found to behave in a manner very similar to *Centropages typicus*, and might therefore afford confirmatory evidence in a comparison with the flow through the Straits of Dover.

Scott (1911) made no comment in the 'Bulletin Trimestriel' on the western restriction of *Isias clavipes*, which seemed to be a regular feature of its distribution on the Recorder lines, but if reference is made to the map summarizing the frequency of occurrence in the area from 1902–08, it will be seen that the species was more often taken in the channel and western half of the southern North Sea than off the Dutch coast or in the Heligoland Bight. There is agreement in the seasonal periodicity for the species, as between 1902–08 the maximum fell in the August quarter, and, as is shown in the histograms of monthly averages (Text-figs. 6, 7 and 8), we found August and September to be the most successful months.

Labidocera wollastoni was described from 1902–08 as an oceanic species, which reaches its maximum between August and November. This again is in agreement with the Recorder data, which showed August and September as the most successful months for the species.

As was stated earlier, *Anomalocera patersoni* was found in the Recorder material on two occasions only. This extreme scarcity was surprising in view of the International Council's findings, because it was then recorded to have had a similar distribution and periodicity to Labidocera, but to have been, if anything, more common. A possible explanation lies in the common supposition that the species usually swims near the surface, and if this is so the Recorder may, at 10 metres, pass too deep to catch it. Sars (1903, p. 141) stated that it might be found so near the surface that it might break the surface. Gough (1905) was more definite when he remarked that it rarely descended to 10 metres, and Savage (1926) took it only in surface hauls. Again, Gibbons (1936, p. 28), after commenting on its importance as a food of the herring, wrote: "It is . . . located almost entirely in the surface layers of the sea. Even when occurring in large numbers it is frequently found only in the surface net, the two lower nets, and especially the bottom net, rarely taking more than one or two individuals." Russell (1927b), on the other hand, found in the Channel in 1925 that the species was restricted to the upper few metres in April, May and June, but showed signs of spreading into deeper water in July and August, which was the time when it became more abundant in the area. If this is a general phenomenon and the conclusion that Anomalocera is almost exclusively a surface form is a fallacy based on observations which do not cover the whole year, one is compelled to assume that the 1932–37 period was a particularly unsuccessful one for this species. This seems unlikely in one respect, because in 1932 and 1933 and to a lesser extent in 1934 Savage (1937) found it to be quite well represented in the stomachs of herring taken from the Shields area, which is not far removed from the Copenhagen line. During this period, however, no Labidocera were recorded in the stomach contents. Hardy

(1924), on the other hand, showed that the North Sea herring would take both species, and as Labidocera did occur in appreciable numbers on the Recorder lines from 1932–34, the most reasonable assumption is that both species were present in our area, but the vertical distribution of Anomalocera prevented it being caught at 10 metres.

In the 'Bulletin Trimestriel' *Parapontella brevicornis* was described as a tychopelagic form recorded mostly from the southernmost North Sea and the English Channel. The Recorder findings are in agreement with this, as the species was almost entirely restricted to the Rotterdam line. There is some disagreement, however, in the seasonal distribution. Whereas from 1902–08 the maxima fell in the August quarter and the minima in the winter, all the appearances of this species between 1932 and 1937 were in October and November with the exception of two. This may be due to the fact that its appearance in the Recorder samples was correlated with the increased turbulence and vertical mixing associated with the winter, while during the summer months it remained too near the bottom to be caught.

From the 1902–08 data Farran decided that the presence of *Metridia lucens* was indicative of the presence of Atlantic water. He described it as an inhabitant of the North Atlantic which increased very rapidly on meeting favourable conditions in coastal waters, and suggested that the high concentrations so formed followed the oceanic current both round the Shetlands into the northern part of the North Sea and up to the western end of the Channel. He found that effectively the southern limit of its distribution was conterminous with the Scottish observations, which are well north of the 55° parallel.

Candacia armata was another species which appeared from the International Council's results to be oceanic, as it was generally present in the Channel and Northern North Sea. Scott, however, commented particularly on the fact that it was never caught in the North Sea south of a line drawn between the Firth of Forth and the Skagerrak.

Metridia lucens and *Candacia armata* should then prove to be two good indicators of the extent of the Atlantic influence. Apparently from 1902–08 they were not carried into the Southern North Sea.

Turning to the Recorder results it will be seen that although not common, these species were by no means absent from the area between 1932 and 1937. In fact they penetrated as far south as the Humber region during the winters of 1932–33 and 1933–34. Metridia was taken in November, 1933, and March, 1934, and again in the following November, while Candacia was taken in October, 1932, and in November and January of the 1933–34 winter. It is interesting to note that not only were these two species taken farther south during these winters than might be expected from the earlier results, but at the same time *Centropages typicus*, another oceanic form, was far more successful than usual. Metridia, however, was relatively abundant in January and February, 1937, when Candacia was not found, and when *Centropages typicus* was at a very low level.

These species will be considered in relation to the prevailing physical conditions and water movements in a future paper.

Summarized Distribution of the Copepoda in the Area.

Having presented the Recorder material and made some broad comparisons between it and earlier results, it remains only to draw attention to the more striking points arising from it.

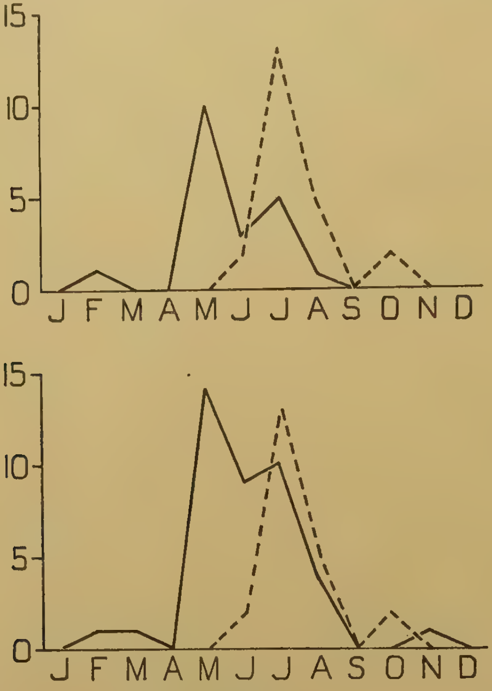
First we may consider the changes which take place during the year. There are quite obviously very marked and significant differences between the years, but nevertheless there are a number of common points which serve as a basis for comparison. It will be remembered that there is a degree of consistency between the winter months of all years and so the winter is a convenient time at which to begin. December or January are typical months, in which there appears a low and even distribution over most of the area, and a band of higher concentration off the Dutch coast. This coastal restriction has been shown by other workers. Savage (1923), during the 'Plaice Egg Cruises' of the 1920–21 winter, found in January and February higher numbers on the eastern side of the area, whereas in December he took more off the East Anglian coast, so that there appeared between December and January a swing of the main part of the population from west to east. He correlated this with the winds prevailing over the periods just previous to his observations, and concluded that the change was due to a heaping effect off the Dutch coast of the surface water driven by south-west winds. This is in agreement with the principle suggested by Gran (1912), who commented that the prevalent winds tended to drive the surface layers towards the coast in the autumn and so accumulate large quantities of plankton there. It is not easy to assess the degree of this restriction or apparent heaping effect in the various years, as it obviously is bound up with the number of individuals present, a number which varies very considerably itself, so it is not practicable to attempt at this stage any comparison between the distribution and wind data. It is interesting, however, that the composition of the eastern population on both the Bremen and Rotterdam lines is very similar to that in the rest of the area sampled, and although at times, as for example in the 1933–34 winter on the Rotterdam line, there is a comparatively sharp boundary between the regions of higher and lower densities, there is more often a quite gradual change from one end of the line to the other. There is, in fact, no evidence to suggest that these higher numbers are part of a distinct community of different origin to the individuals that are scattered over the rest of the area, but it seems more probable that it is the result of an accumulation of the type suggested by Gran and Savage. The way in which a more even autumn distribution gradually gives way to the eastern preponderance gives some confirmation of this; the best example is the autumn of 1937, when there is data for practically every week on the Bremen line, and the eastward movement of copepods appeared to be both gradual and continuous (see Text-fig.

12). In addition to the spatial arrangement there are other characteristics of the winter copepod population. A number of species appear in the area only at this time of year. These fall into two categories. The first includes *Centropages typicus* and the cyclopoid *Corycaeus anglicus*, both of which regularly appear in the autumn and persist until the end of the year. Reference to the maps illustrating the distributions of these two forms shows that they by no means invariably have similar spatial arrangements at first, but in every case they show signs of conforming to the typical winter pattern before they disappear. The second consists of two larger forms, *Candacia armata* and *Metridia lucens*, which are most certainly not indigenous to the area but have a natural habitat further north, and are only carried as far south as the Recorder lines by the influx of higher salinity water. Two other species occur almost exclusively in the winter, *Parapontella brevicornis* and *Alteutha interrupta*, but as both of these have a bottom habitat it is probable that their appearance in our records at this time is associated with the increased turbulence.

In the spring or early summer there occurs an increase which may in some years (1935 and 1937) be very pronounced. The dense population found over the Dogger Bank and on the Bremen line at this time is in the main composed of *Pseudocalanus elongatus*. *Temora longicornis*, *Acartia clausii* and *Paracalanus parvus* are well represented, although there is some evidence that the last named species does not reach its maximum until the autumn. In addition there are a number of less common forms, such as *Centropages hamatus* and *Acartia longiremis*, while by midsummer *Isias clavipes* and *Labidocera wollastoni* appear.

This spring improvement in the population in our particular area may be produced in two ways. Firstly there is the possibility of large numbers of copepods being carried into the area at this time of year from some more densely populated region adjoining it, and secondly the possibility of a sparse population that has wintered in the Southern North Sea breeding there to produce a new and more abundant stock. It is of course most probable that both of these occur and the summer population is the combined result of local breeding and invasion, but it would be valuable if possible to determine the extent of each effect in order to know where to look for the factors controlling the success of the population or the available fish food in any year. The distributions found during the years of the survey indicate that if not the actual individuals the factors controlling their production come from a region north of the Copenhagen line. On the maps showing the " total Copepoda " distribution (Plates XCIV–CVI) it will be seen that, if the Dutch coastal concentration is neglected, the first indications of higher numbers appearing amongst the general sparse winter population were usually found on the western half of the Copenhagen line: March, 1933, April, 1934, and April, 1937, being particularly good examples of this.

Another point in this respect is that the population in the southern part of the area sampled by the Rotterdam line was never affected by spring and summer to anything like the same extent as the two more northern lines. In fact, as has been pointed out earlier, the difference between the summer and winter populations on this line may not be very marked (see Text-fig. 6). In addition to this the various species tend to reach their maxima later here than on the Copenhagen and Bremen lines. This is illustrated by Text-fig. 13, where the continuous line graphs showing the frequency with which the summer species reach their annual maxima in the different months during the years 1933–37 on the Copenhagen line (upper graph) and the Bremen line (lower graph) are compared with broken-line graphs, each showing similar data for the Rotterdam line. The species included in this figure are all those given in Text-fig. 6 except the two winter species *Centropages typicus* and *Corycaeus anglicus*. It will be seen that whereas the maxima for the summer species on the Rotterdam line occurred most frequently in July and August, on the two northern lines the majority fell in May, June and July.



TEXT-FIG. 13.—For explanation see accompanying text.

A COMPARISON OF THE FIVE-AND-A-HALF YEARS.

Finally, it may be convenient to sum up as briefly as possible the characteristic points of the various years investigated.

The information available for 1932 consists only of Bremen records for the later part of the year and Rotterdam records for November and December. This, however, is sufficient to show that it was a particularly successful autumn for most species. This was most marked in the case of *Temora longicornis* and Acartia spp. The Para- and Pseudocalanus group was above average and *Isias clavipes*, *Centropages hamatus* and *Labidocera wollastoni* were well represented. Of the winter species, *Corycaeus anglicus*, although quite abundant at the end of the November record, appeared to have a short season, but *Centropages typicus* was plentiful on the centre of the Bremen line over quite a long period. Both *Candacia armata* and *Metridia lucens* were taken.

Although the successful preceding autumn crops were reflected in the early months of 1933 for some species, this was, on the whole, the leanest year of the survey. All the summer species with the exception of *Isias clavipes* and possibly *Centropages hamatus* and *Labidocera wollastoni* were well below their usual level, the failure of the mid-summer Para- and Pseudocalanus population being most pronounced. There was, however, an improvement towards the end of the year, when *Centropages typicus* and *Corycaeus anglicus* were widespread and in places plentiful, and the two exotics, *Candacia armata* and *Metridia lucens*, again appeared.

1934 was an average year. The main species were well represented, but never particularly abundant. *Labidocera wollastoni* and *Corycaeus anglicus* were more successful than usual, while *Centropages typicus* was the less so.

1935 was marked by the very high production on the northern lines in the spring and summer. This was in the main due to the Para- and Pseudocalanus group, but the numbers of *Temora longicornis* and Acartia spp. were also much higher than usual. With the exception of *Labidocera wollastoni* on the Copenhagen line, however, this was not a successful year for the other less abundant species. *Isias clavipes* and *Centropages hamatus* were at about their normal density, while both *Corycaeus anglicus* and *Centropages typicus* reached a very low level, the latter only occurring on the Rotterdam line in June. In fact this winter appeared to be most unfavourable for the copepod population. A relatively small proportion of the enormous summer Para- and Pseudocalanus stock persisted through the autumn, but all the other species became sparse, and during the early months of 1936 this was the only group present in appreciable numbers.

The summer months of 1936 were rather like those of 1934. The main species were less numerous than in 1935, but more successful than 1933, and the winter species were again as in 1935 very poorly represented. *Centropages typicus* was never abundant and *Corycaeus anglicus* only recorded as present. Acartia spp. were outstandingly successful in the spring or early summer; with 1935 it was the most successful period for this group during the five-and-a-half years.

As in 1936, the early months of 1937 supported only a very weak population. Low numbers of Para- and Pseudocalanus were taken, but little else except in a restricted region off the Dutch coast, where a slightly stronger population was made up of this group, *Temora longicornis*, Acartia spp., and a few *Centropages hamatus*. By May, however, a great change had taken place. The Para- and Pseudocalanus group was as successful as in 1935 and *Temora longicornis*, Acartia spp. and *Centropages hamatus* were more abundant than usual. During the subsequent months these forms remained at a high level in the northern part of the area, but there was a marked decrease in their numbers on the Bremen line, while on the Rotterdam they were no more successful than usual. This was a relatively poor year for *Isias clavipes* and *Labidocera wollastoni*. Both *Centropages typicus* and *Corycaeus anglicus* showed a considerable improvement on the two previous poor winters, and the northern form *Metridia longa* returned to the area for the first time since the 1933 winter.

As a generalization it may be said that the years with a flourishing summer population were followed by a poor winter, for example, 1935 and 1937 ; whereas in those years characterized by the success of the winter species, the commoner summer forms were less abundant, *i.e.* in 1932, 1933 and 1934. It is interesting to note, however, that in 1935 and 1937 the particularly successful copepod communities appeared just after dense and varied crops of spring diatoms had been found over the Dogger Bank region (see Lucas, 1940).

GENERAL SUMMARY.

1. The monthly changes in the distribution and abundance of the Copepoda in the southern North Sea have been investigated from June, 1932 to December, 1937, by using the Continuous Plankton Recorder ; this was towed at a standard depth of 10 metres, by ships sailing on regular lines from Hull to Rotterdam, to Bremen and towards the Skagerrak, and later from London to Esbjerg.

2. The methods are described and those limitations which apply more particularly to the Copepoda are discussed (pp. 175 to 186 and 198 to 203).

3. The first part of the report deals with the Copepoda as a whole, *i.e.* the total population. The difference between the summer and winter distributions is stressed. The variations in numbers from year to year are found to be considerable and it is suggested that they are sufficiently large to be reflected in the success or failure of the broods of those fish which are at some period of their development dependent upon the Copepoda for food.

4. The second part deals with the data concerning the constituent species or groups of allied species ; a list of these is given on p. 197.

5. The group Paracalanus + Pseudocalanus was by far the most abundant and together with the genera Temora and Acartia was found to be responsible for most of the fluctuations in the population (pp. 205 to 208).

6. The distributions, seasonal and spatial, of the other common forms are described, with the exception of that of *Calanus finmarchicus* which is to be the subject of a later report.

7. The recorder results are compared with the findings of the International Council survey from 1902 to 1908 ; some marked disagreements are discussed (pp. 227 to 232).

8. The appearance of the northern forms *Candacia armata* and *Metridia lucens* during the winters of 1932–33, 1933–34 and 1937 are recorded (pp. 222 to 223).

9. A summarized account of the main seasonal changes in the area is given (pp. 232 to 234) and followed by a brief comparison of the $5\frac{1}{2}$ years investigated.

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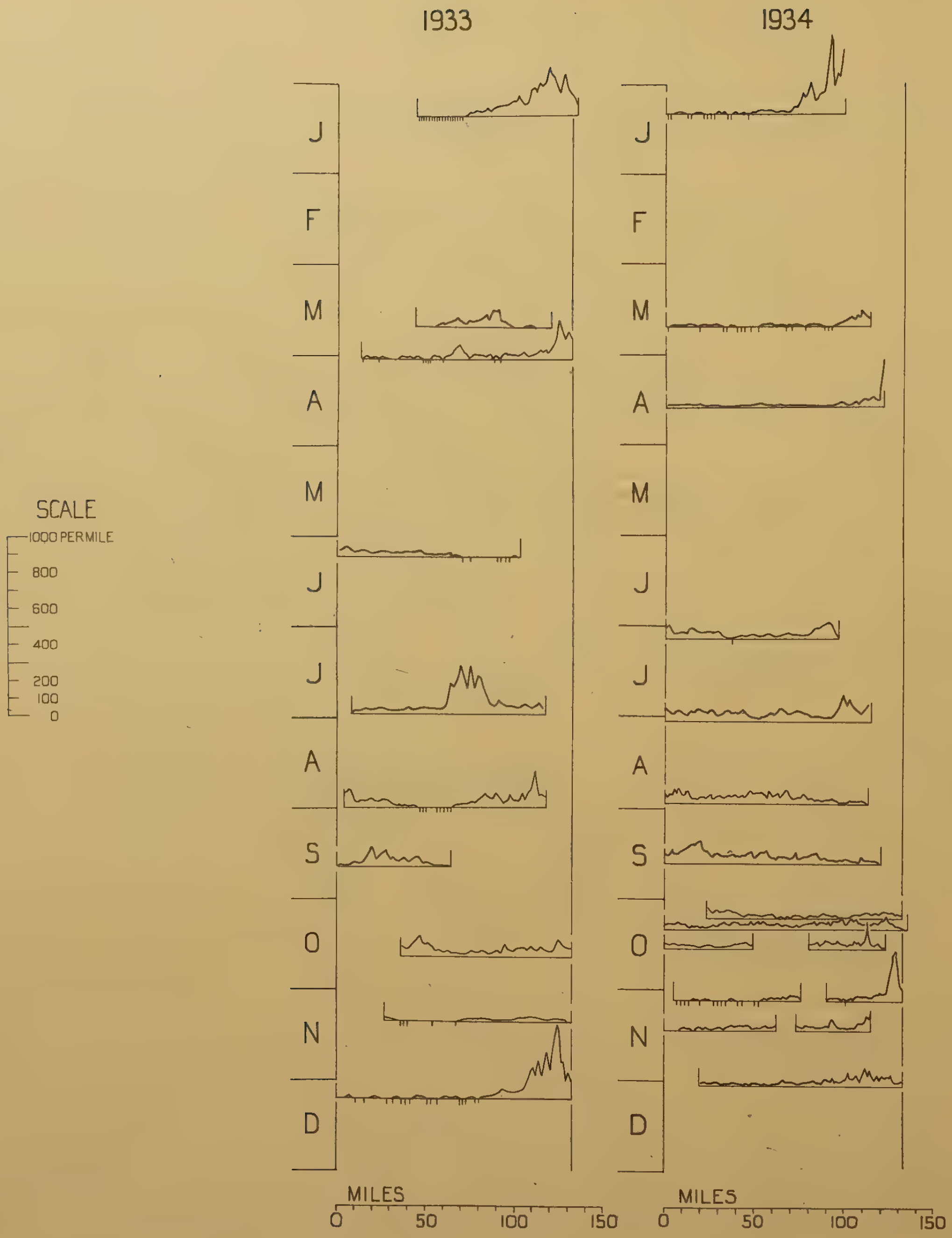
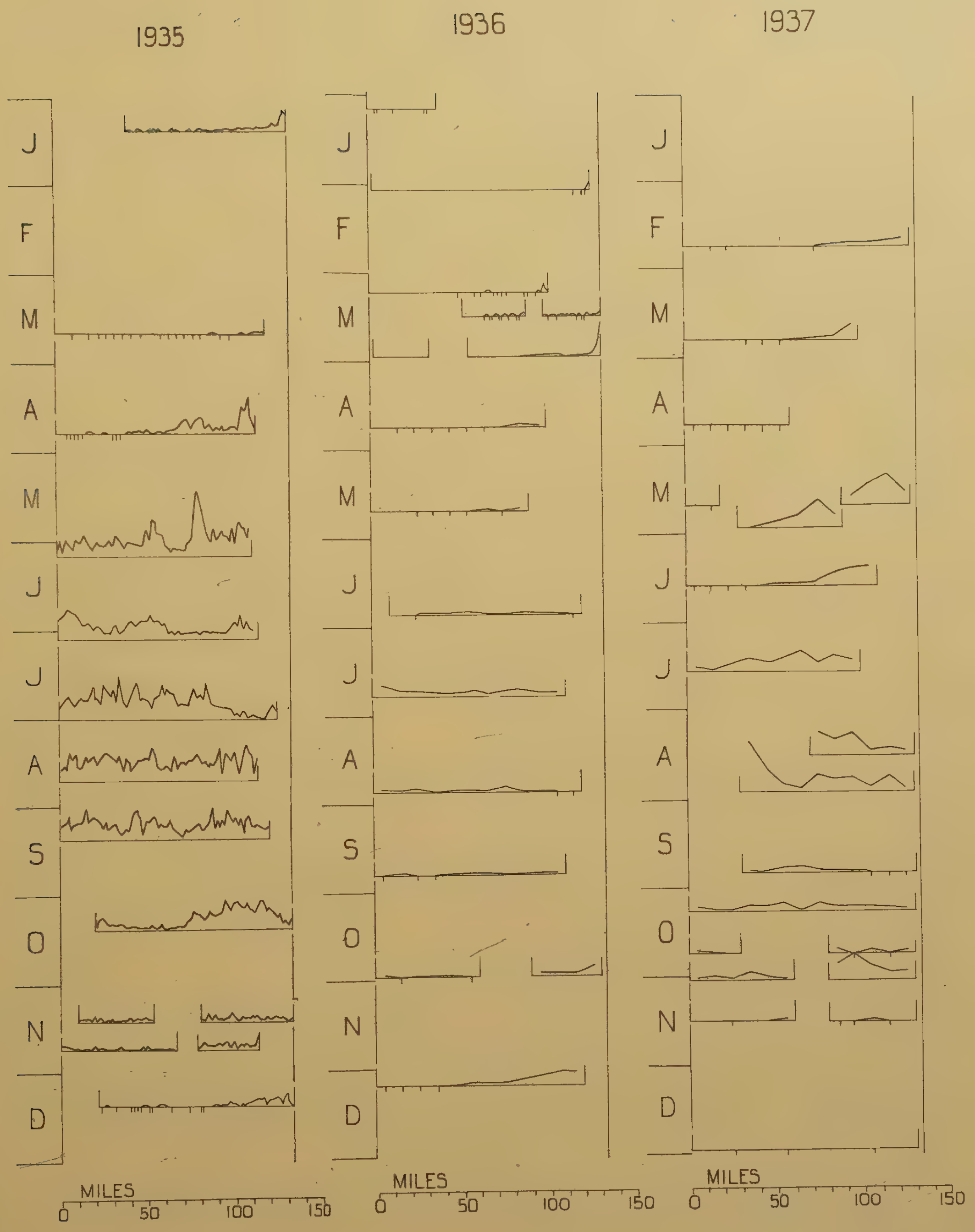
PLATES LXV-XCIII.

SERIAL GRAPHS COMPARING THE VARYING QUANTITIES OF THE PRINCIPAL COPEPODA FOUND YEAR BY YEAR ON THE DIFFERENT RECORDER LINES IN THE SOUTHERN NORTH SEA JUNE 1932 TO DECEMBER 1937.

PLATE LXV

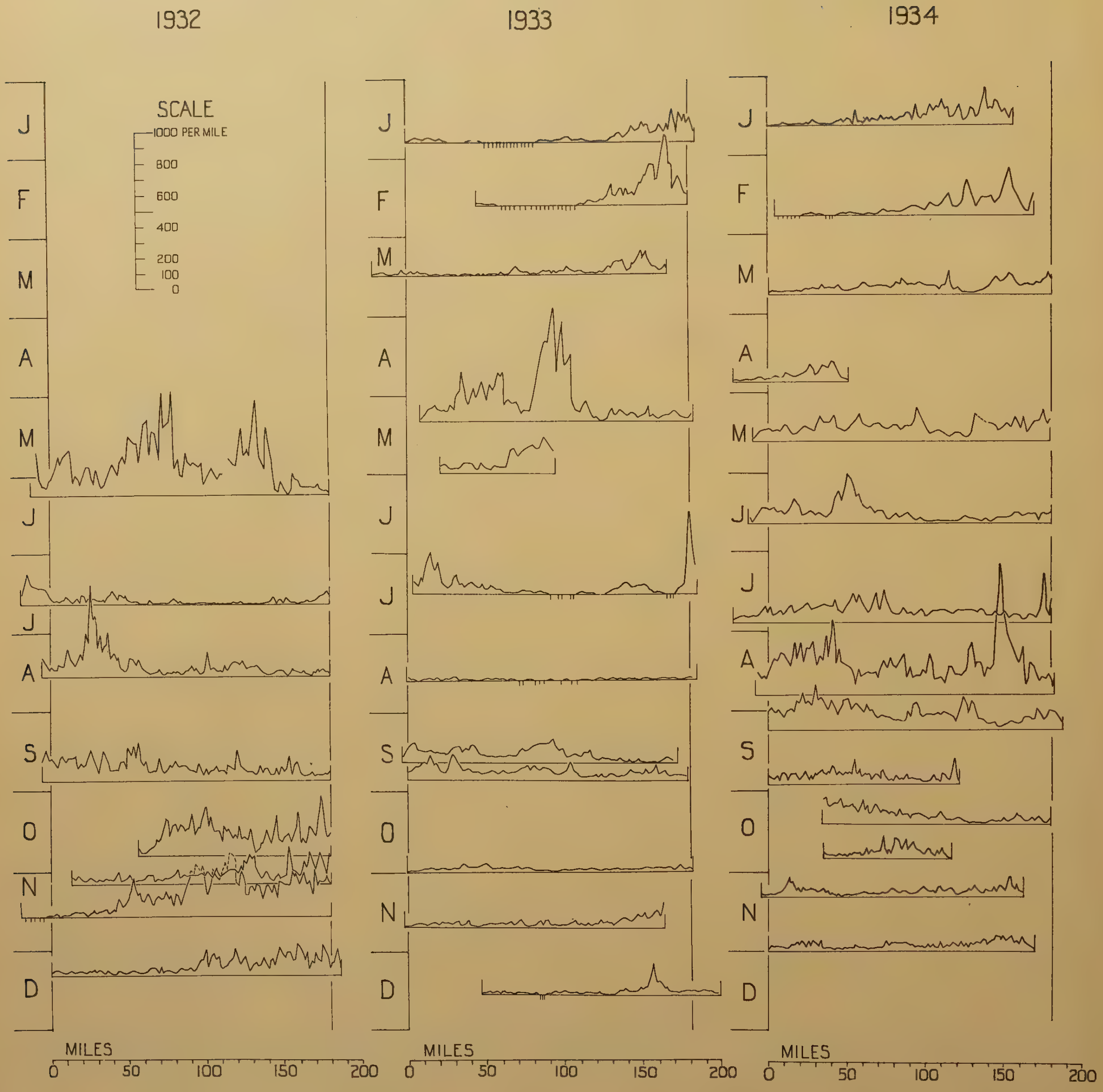


Records of **TOTAL COPEPODA** *on the* Rotterdam *line,* 1933 *and* 1934, *each placed in it's position of date against a vertical scale of months indicated by the letters J. F. M, etc. in each year. The vertical lines to the left and right of each annual series represent the positions of the* East Dudgeon *and* Maas *lightvessels. The estimated numbers per mile are shown as graphs above the base lines and traces (too small to graph) as small vertical strokes below them.*

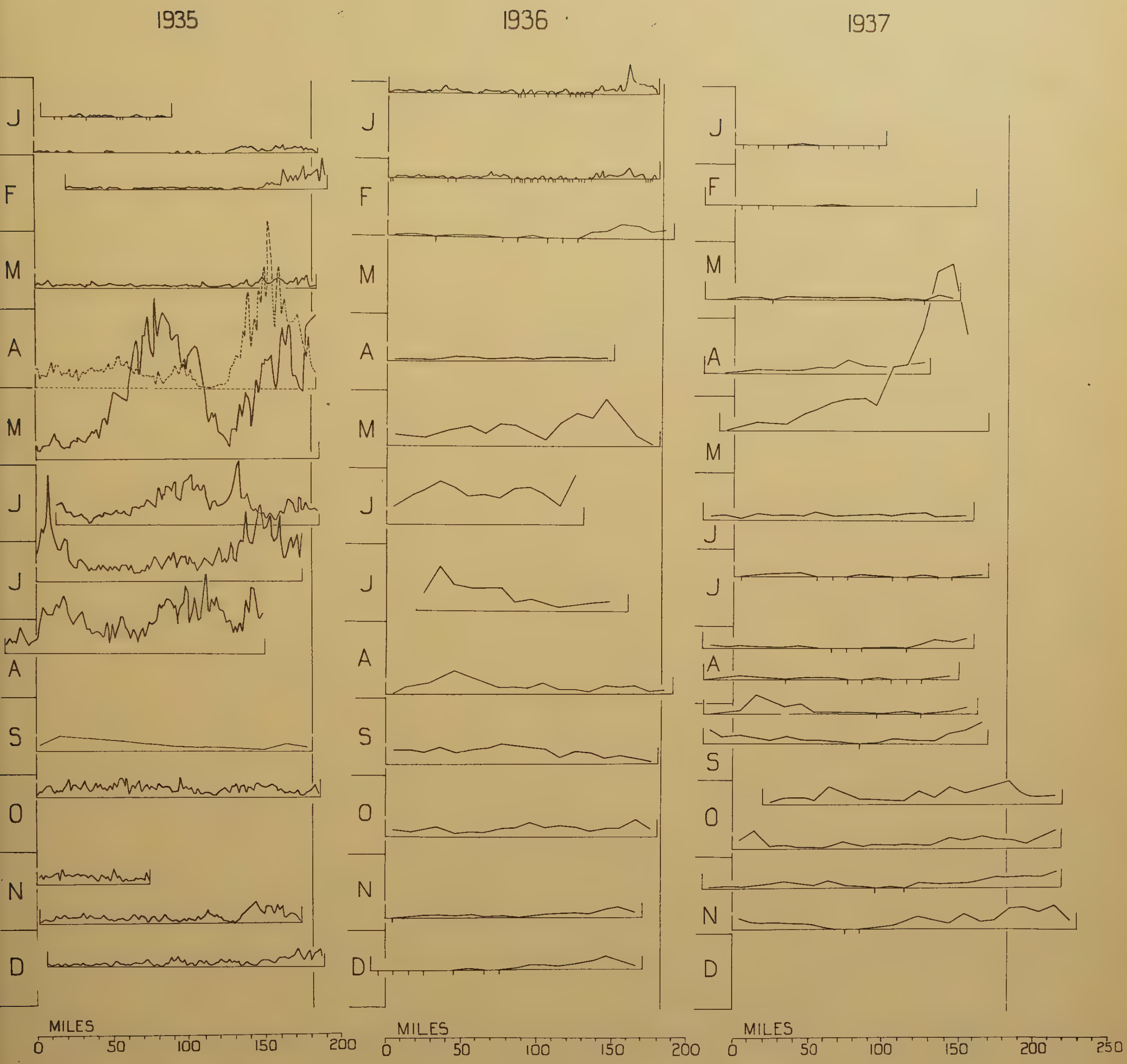


Records of the ***TOTAL COPEPODA*** *on the* Rotterdam *line,* 1935 – 1937, *arranged as on Plate LXV.*

PLATE LXVII

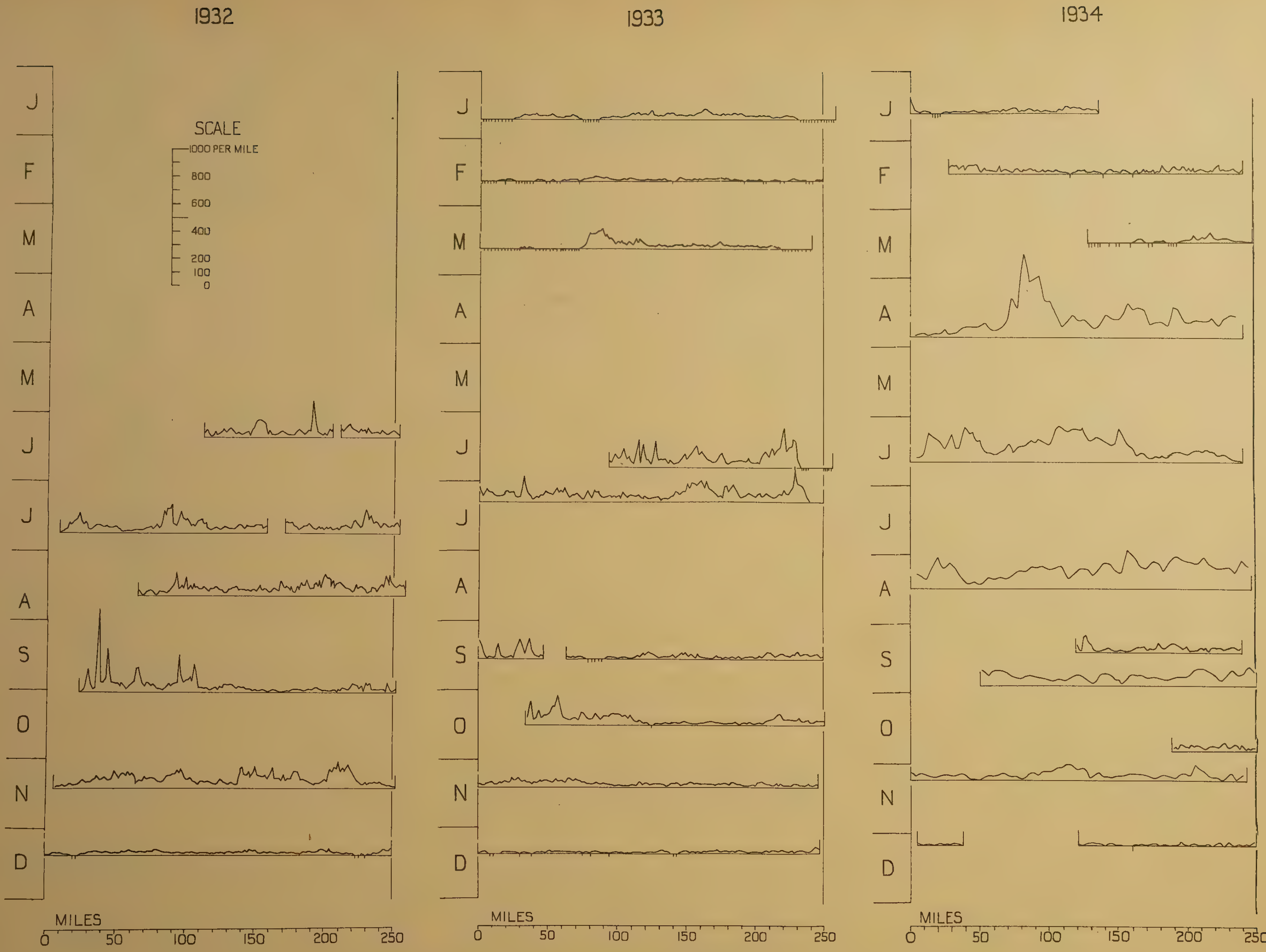


Records of the **TOTAL COPEPODA** *on the* Bremen *lines,* 1932 — 1934, *arranged as on Plate LXV except that the vertical lines to the left and right of each annual series represent the positions of the* Outer Dowsing *and* Borkum *lightvessels.*



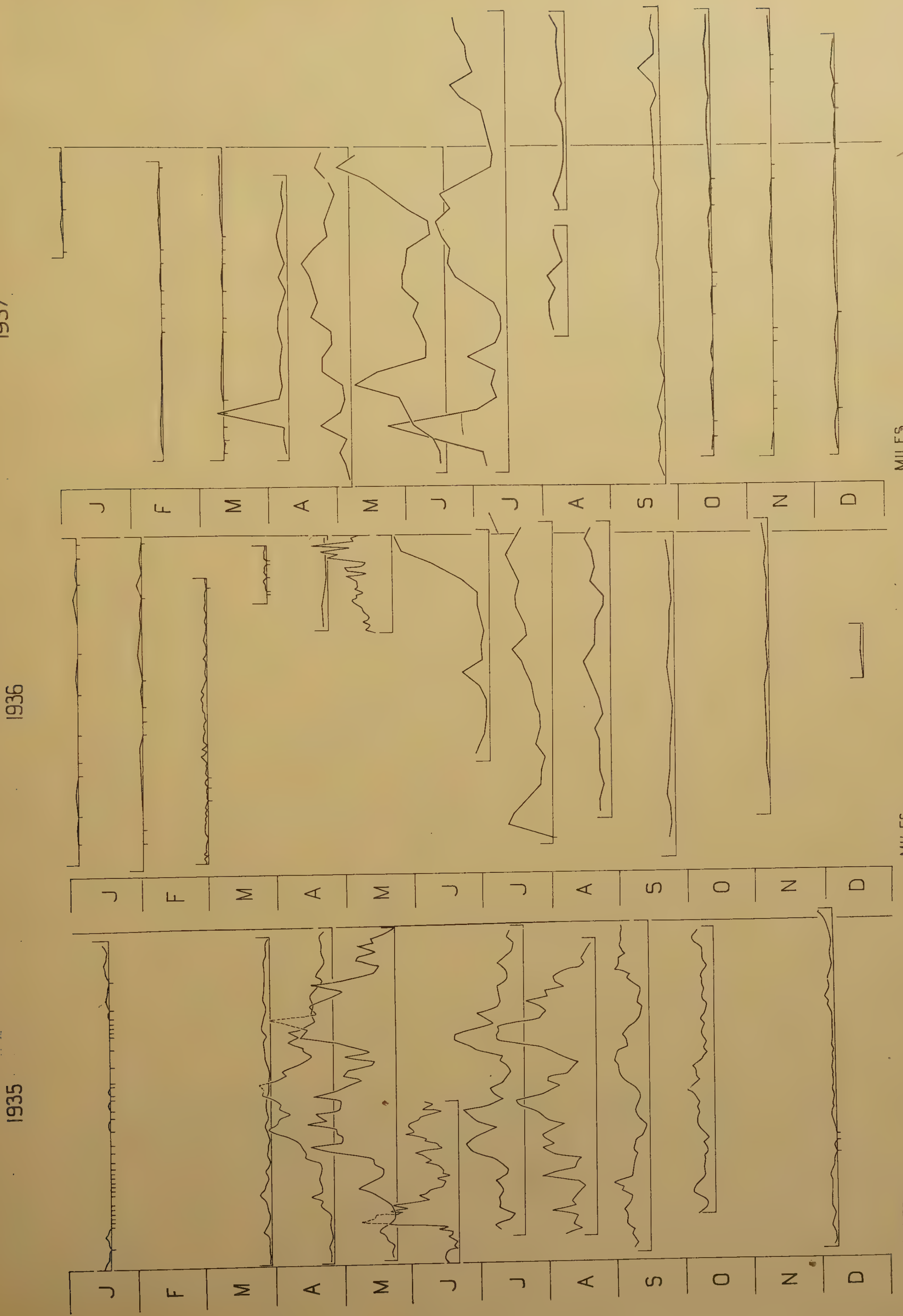
Records of the ***TOTAL COPEPODA*** *on the* Bremen *line,* 1935-1937, *arranged as on Plate LXVII. An overlapping graph is shown in broken line for clarity.*

PLATE LXIX



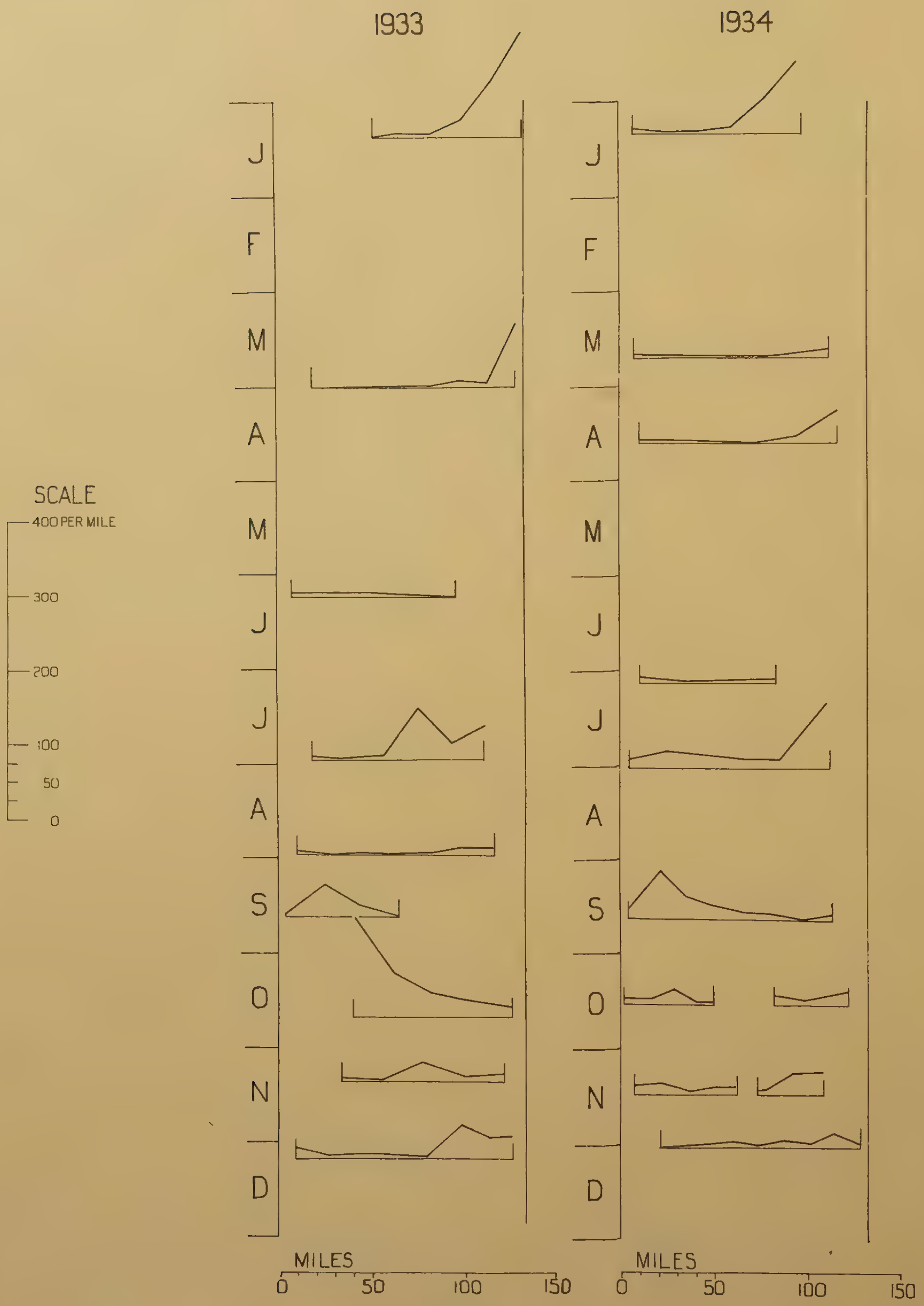
Records of the **TOTAL COPEPODA** on the Copenhagen line, 1932 – 1934, arranged as in Plate LXV except that the vertical lines to the left and right of each annual series represent the positions of the HUMBER lightvessel and a point 250 miles from it.

PLATE LXX



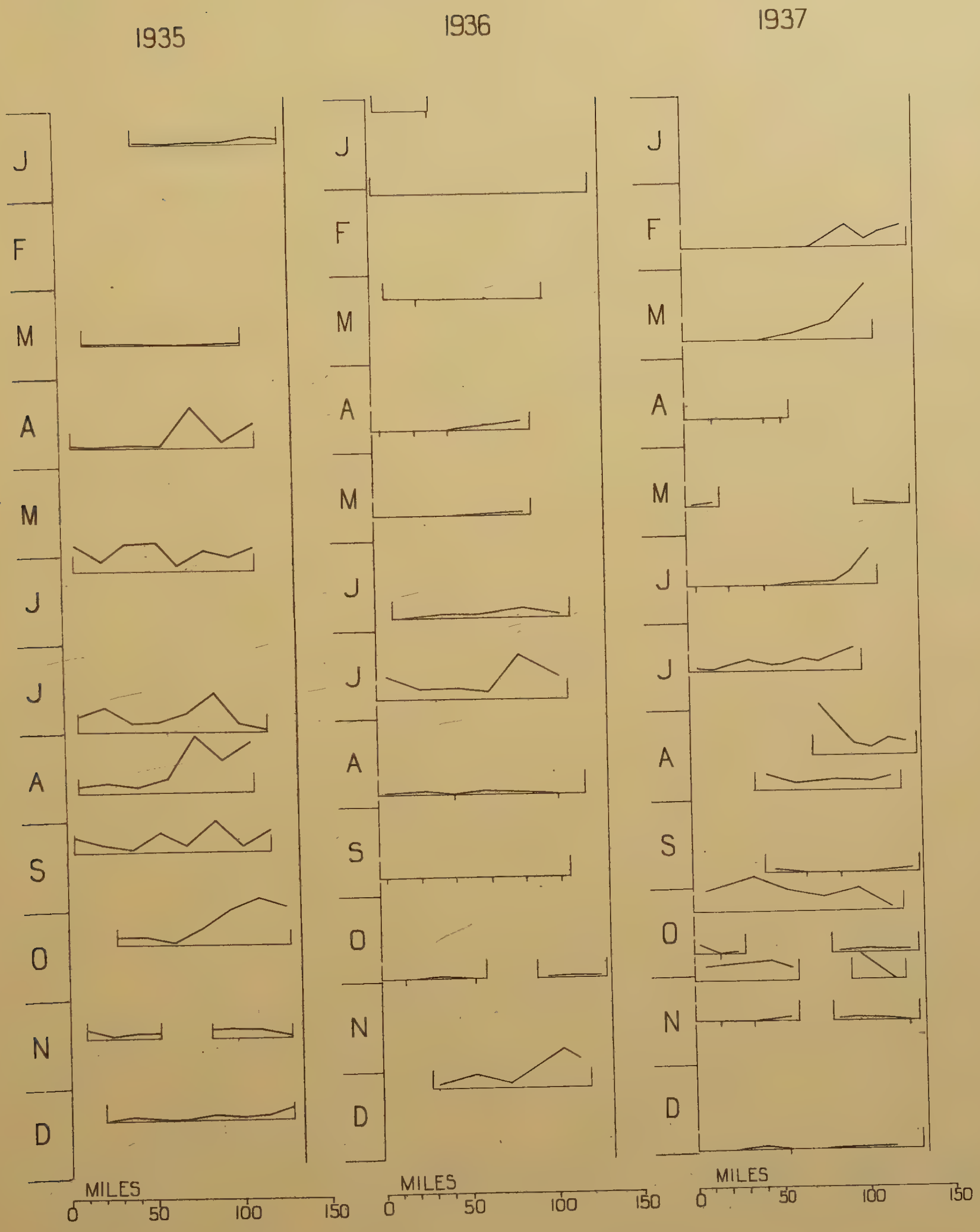
Records of the **TOTAL COPEPODA** on the Copenhagen line, 1935–1937, arranged as on Plate LXIX.

PLATE LXXI



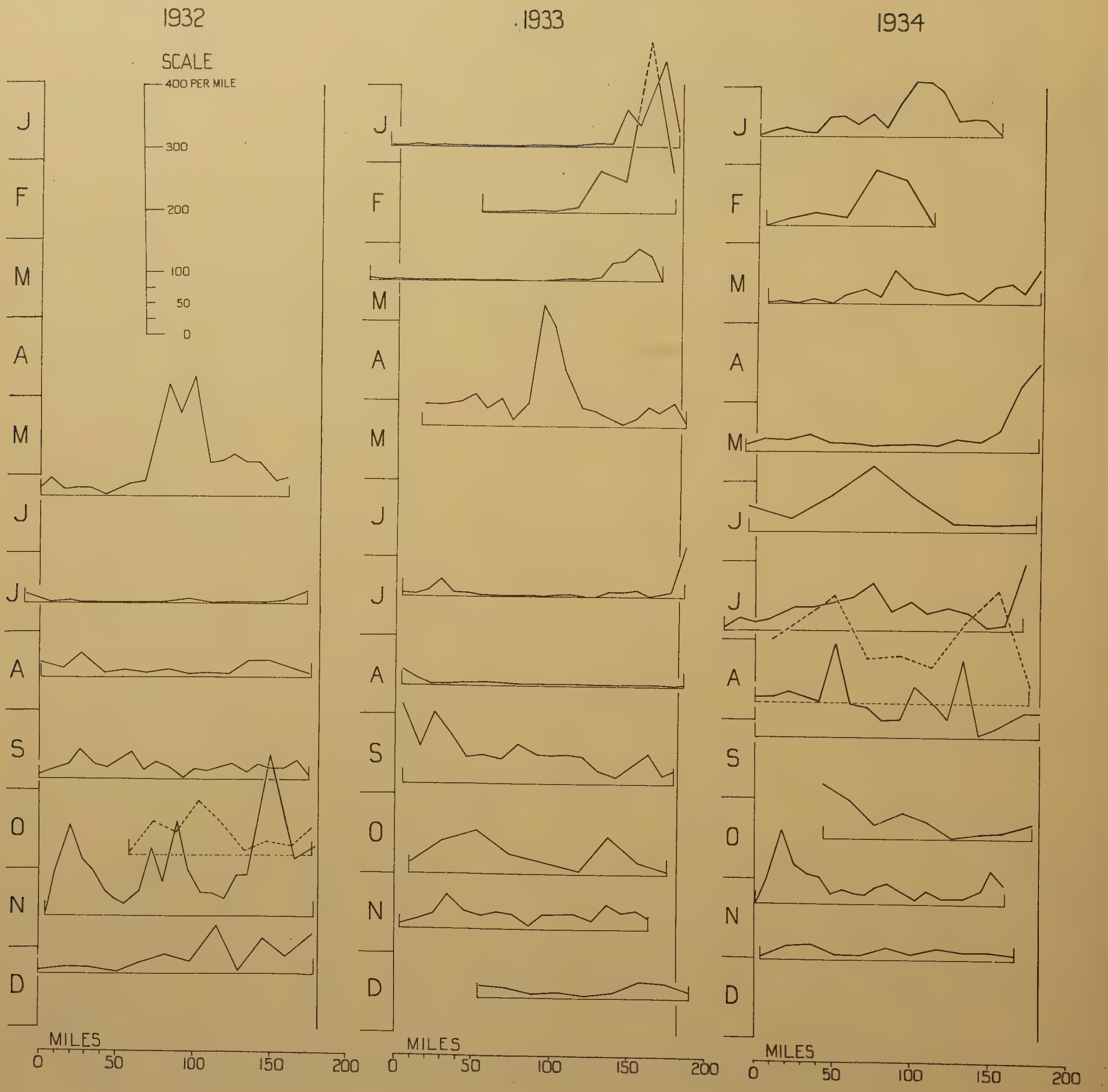
Records of ***PSEUDOCALANUS AND PARACALANUS COMBINED*** *taken on the* Rotterdam *line*, 1933 *and* 1934, *arranged as on Plate LXV.*

PLATE LXXII

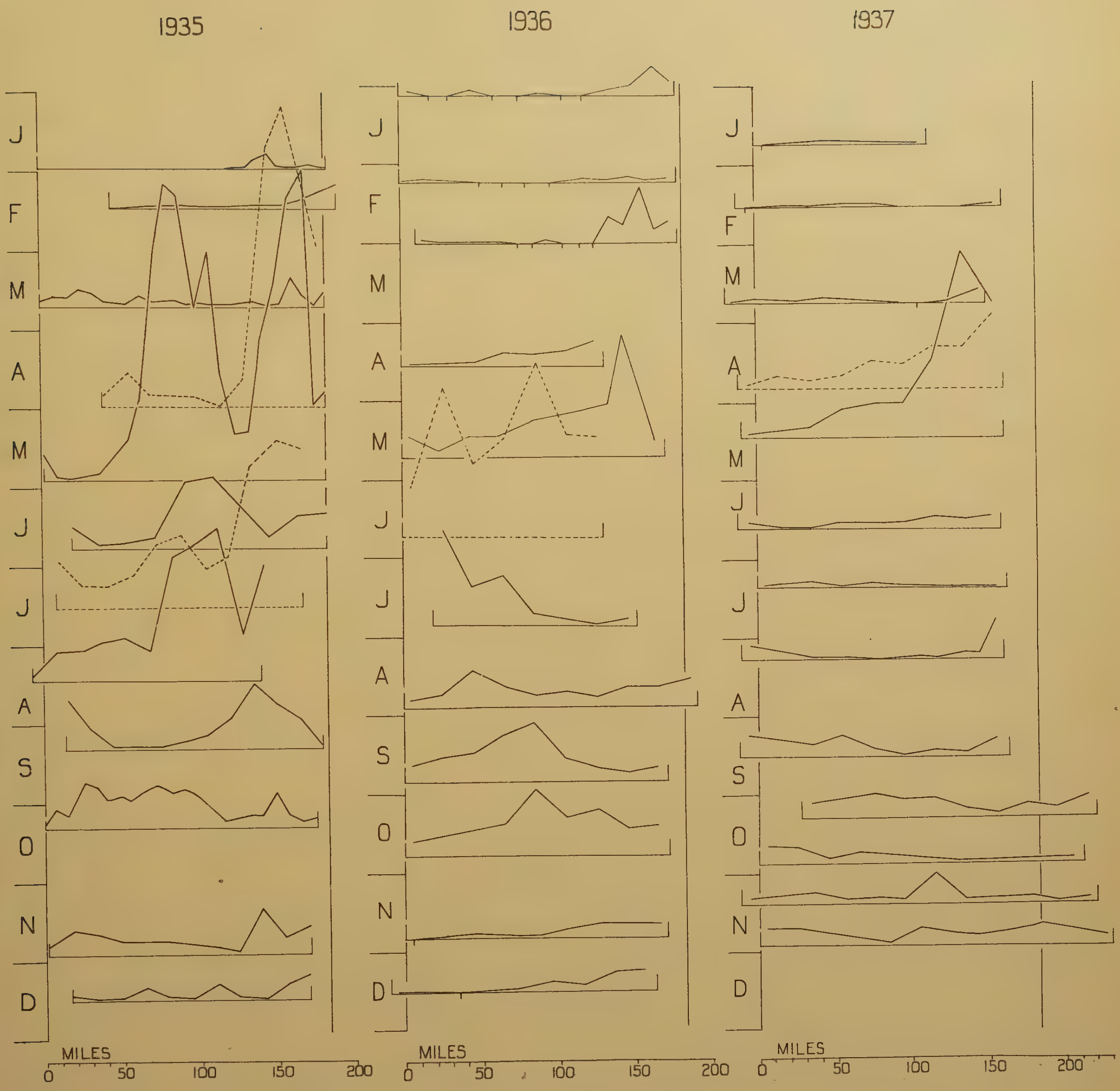


Records of **PSEUDOCALANUS AND PARACALANUS COMBINED** *taken on the* Rotterdam *line,* 1935 – 1937, *arranged as on Plate LXVI.*

PLATE LXXIII

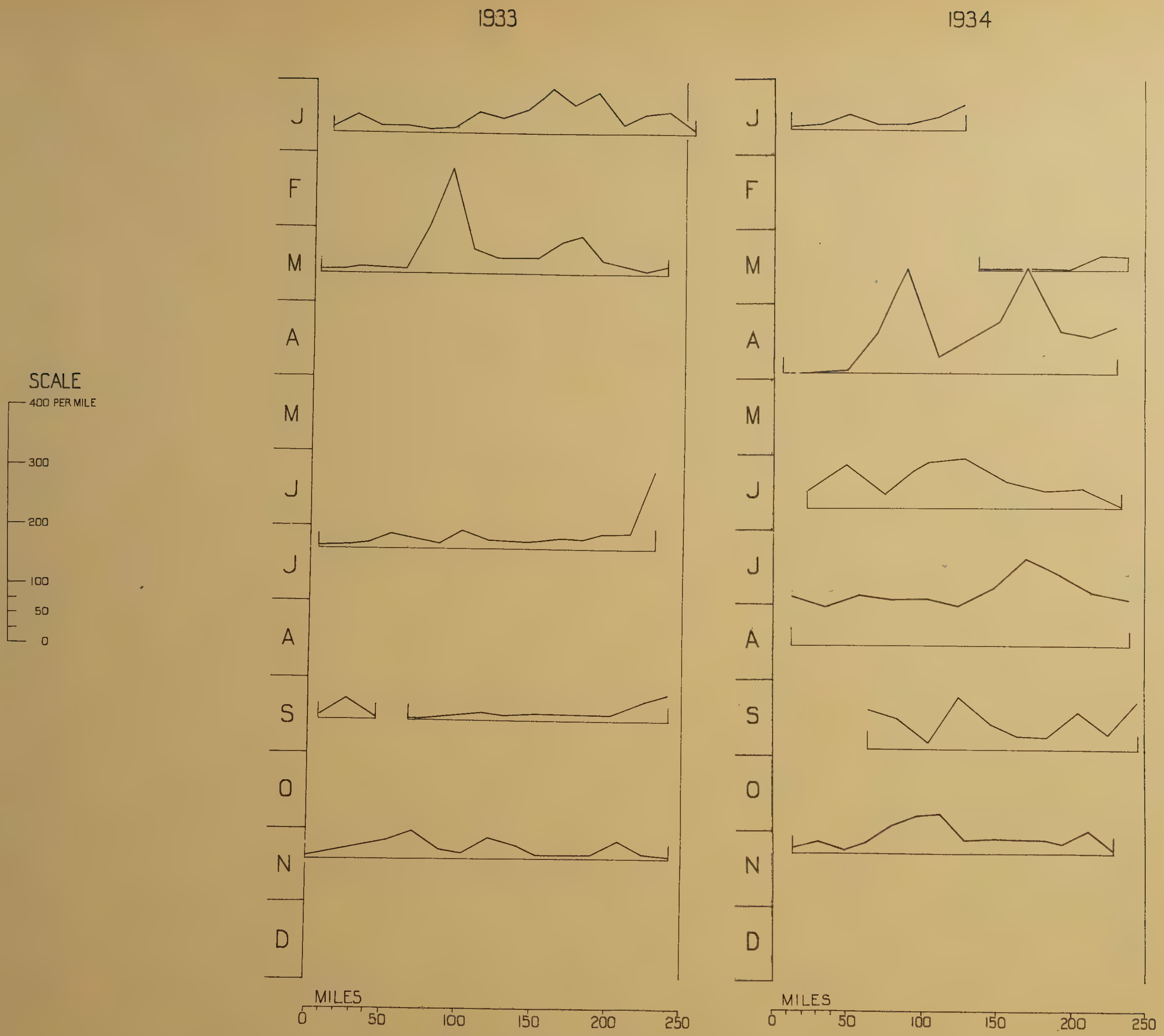


Records of **PSEUDOCALANUS AND PARACALANUS COMBINED** *taken on the* Bremen *line,* 1932 — 1934, *arranged as on Plate LXVII. Overlapping graphs may be shown in broken line for clarity.*

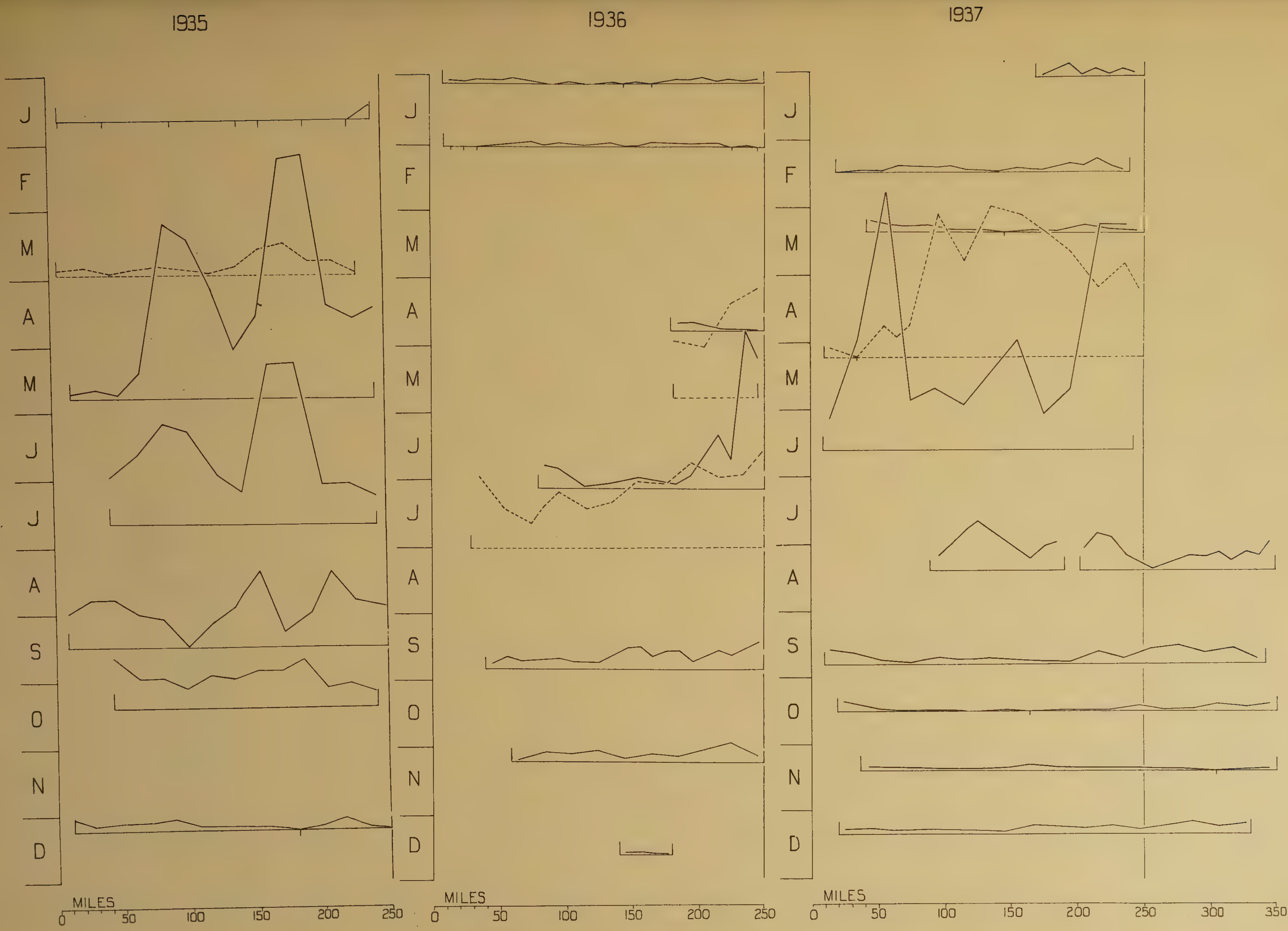


Records of ***PSEUDOCALANUS AND PARACALANUS COMBINED*** *taken on the* Bremen *line,* 1935–1937, *arranged as on Plate LXVIII. Overlapping graphs may be shown in broken line for clarity.*

PLATE LXXV

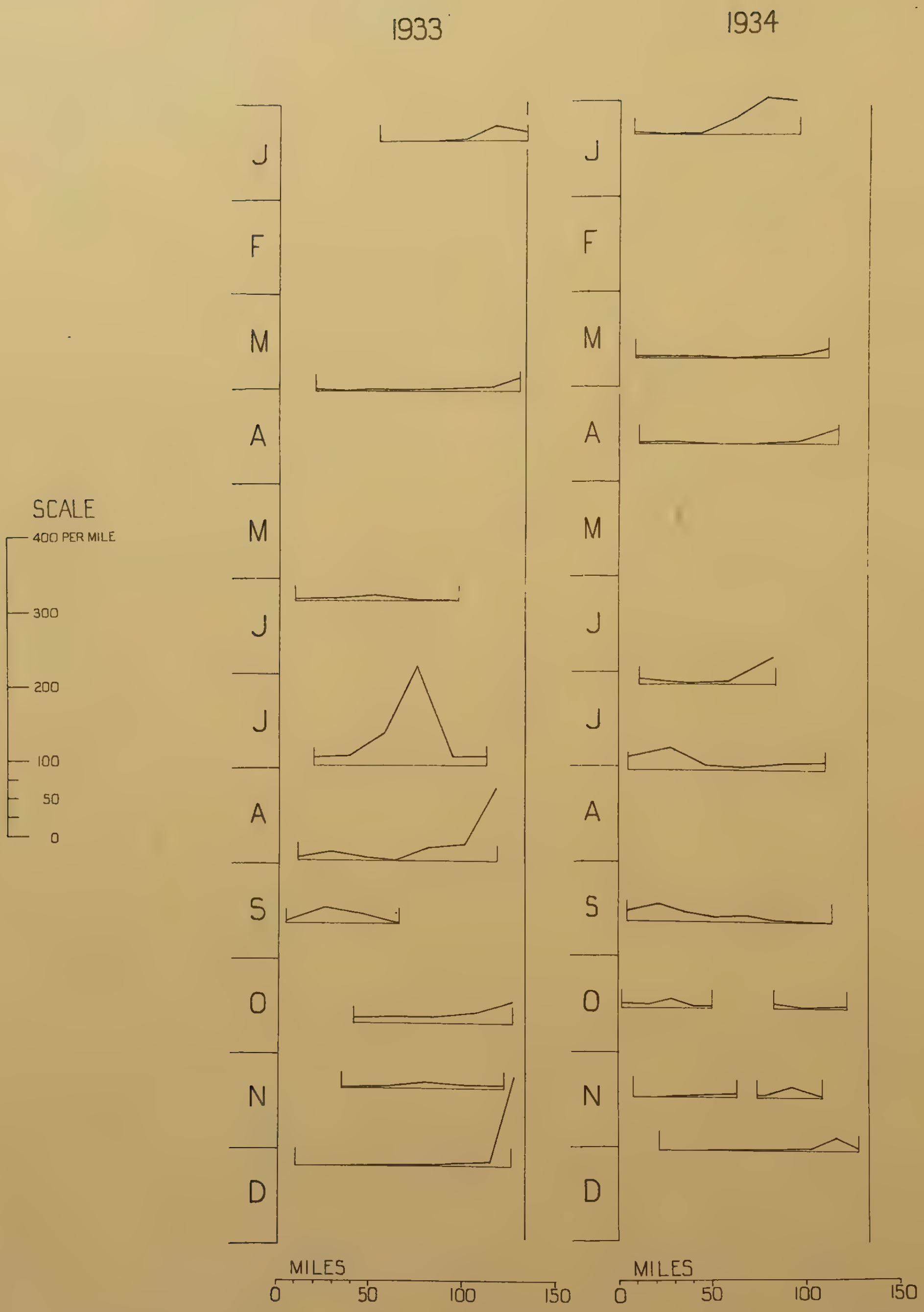


Records of **PSEUDOCALANUS AND PARACALANUS COMBINED** taken on the Copenhagen line, 1933 and 1934, arranged as on Plate LXIX.

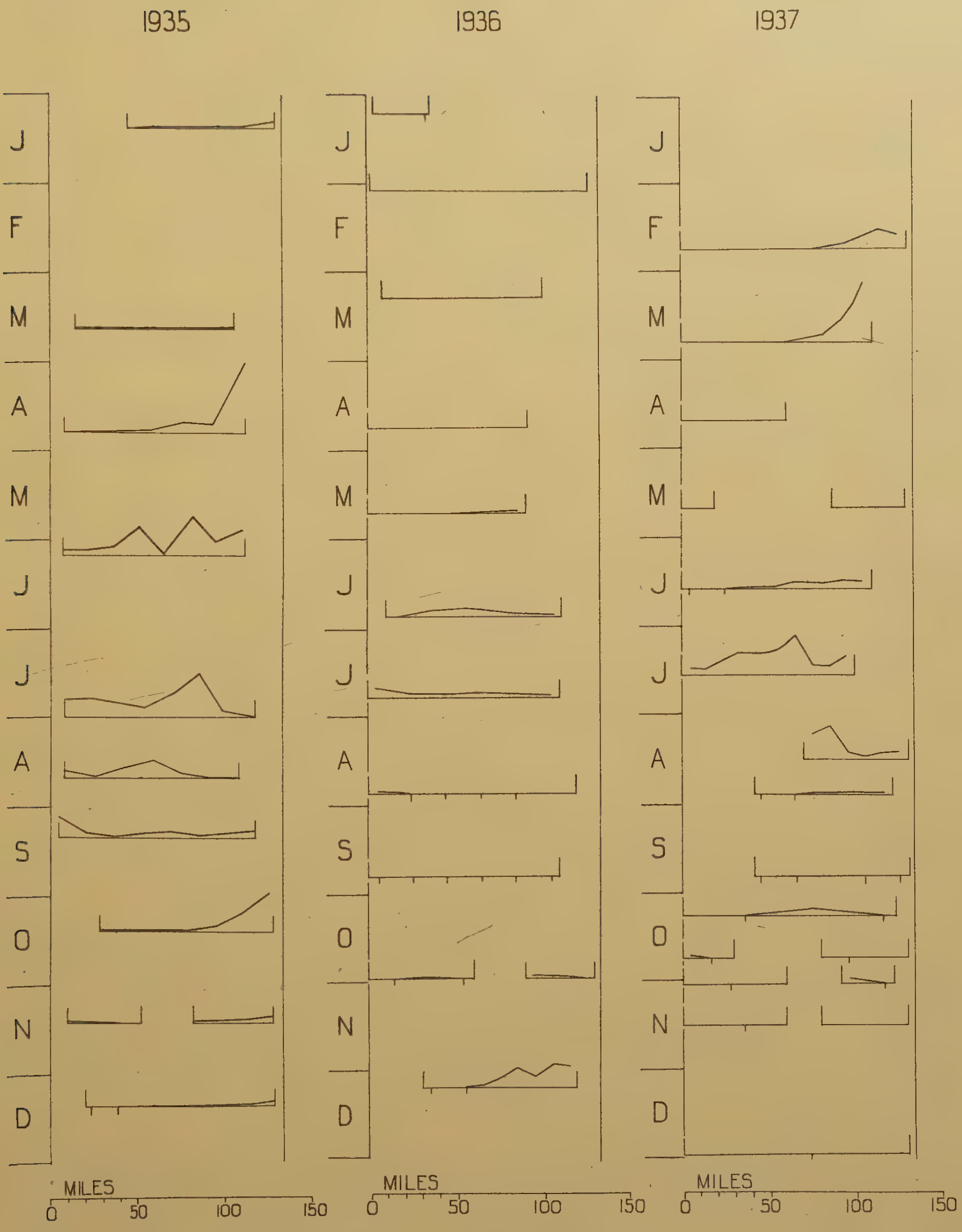


Records of ***PSEUDOCALANUS AND PARACALANUS COMBINED*** *taken on the* Copenhagen *line,* 1935–1937, *arranged as on Plate LXX. Overlapping graphs may be shown in broken line for clarity*

PLATE LXXVII

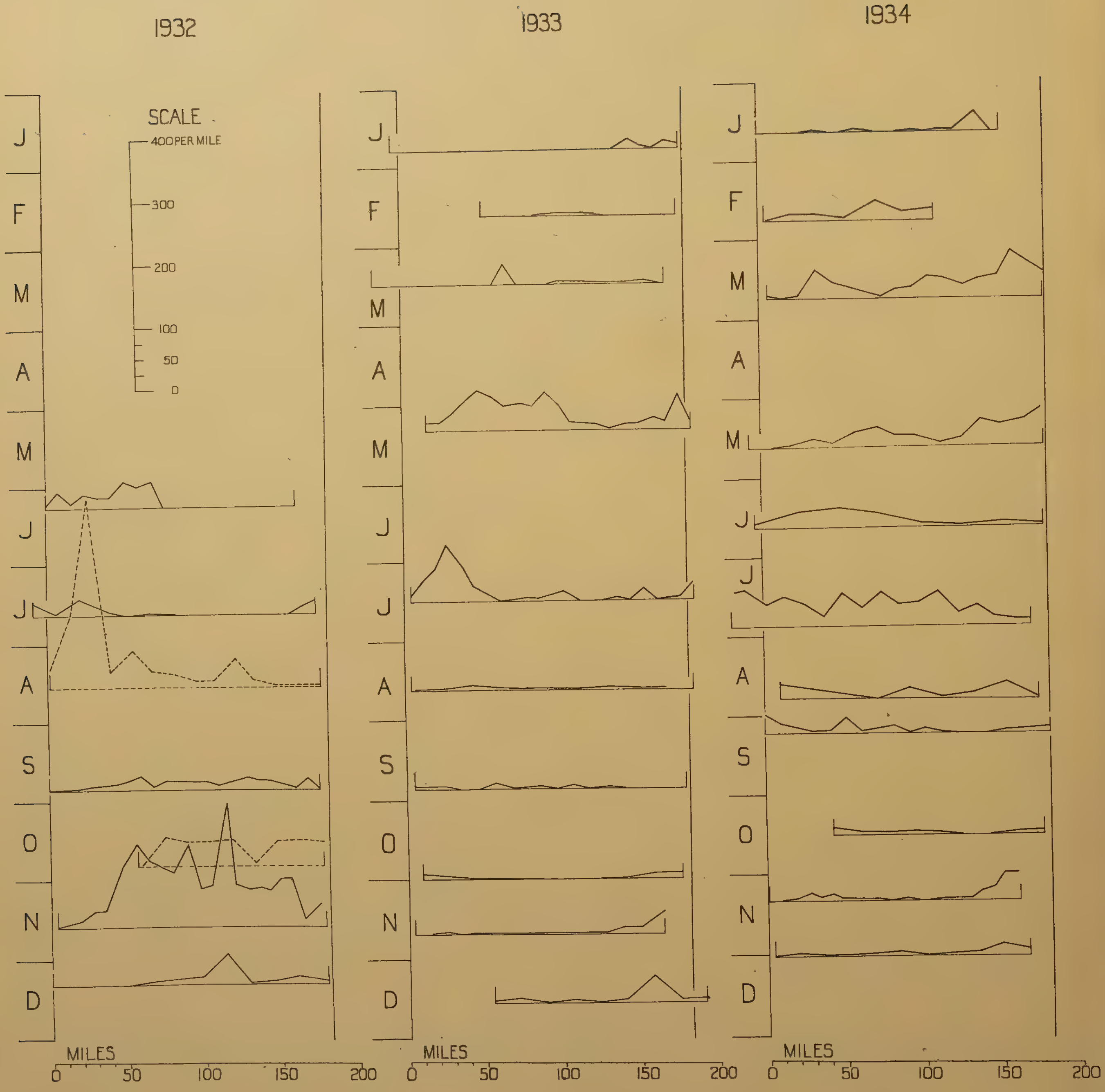


Records of ***TEMORA LONGICORNIS*** *on the* Rotterdam *line,* 1933 *and* 1934, *arranged as on Plate LXV.*

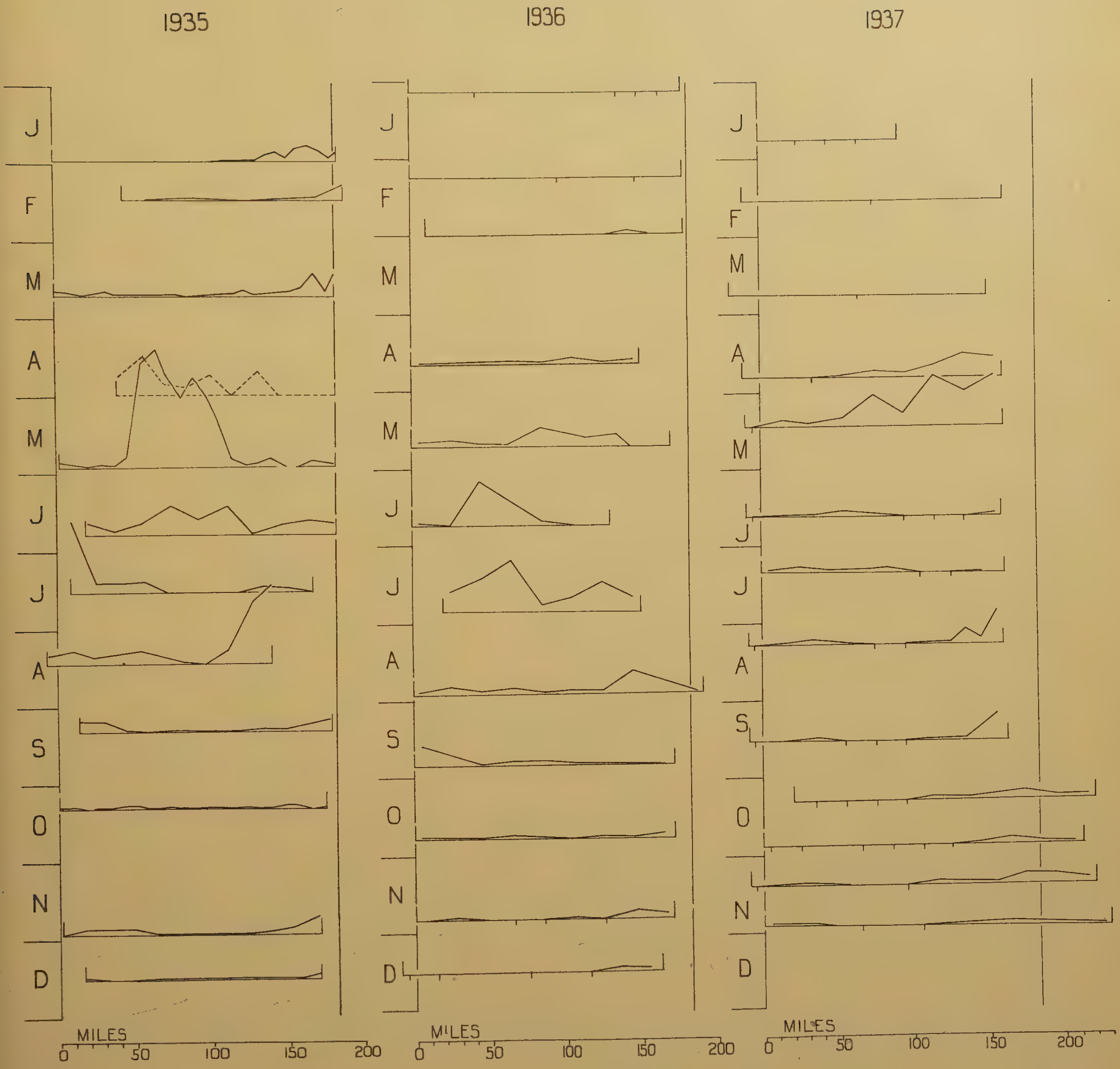


Records of ***TEMORA LONGICORNIS*** *on the* Rotterdam *line*, 1935 — 1937, *arranged as on Plate LXVI.*

PLATE LXXIX

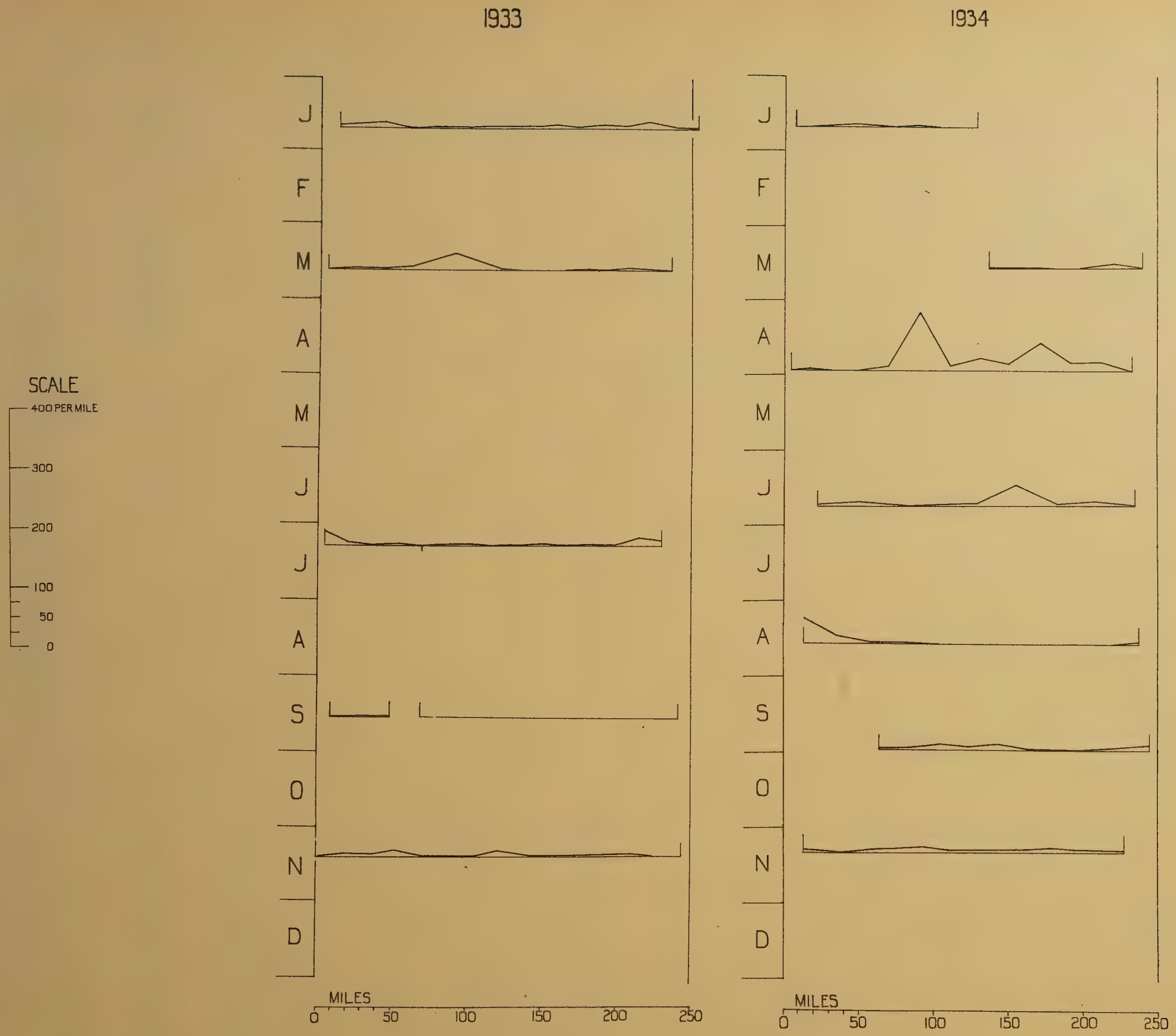


Records of ***TEMORA LONGICORNIS*** *on the* Bremen *line*, 1932–1934, *arranged as on Plate LXVII. Overlapping graphs may be shown in broken line for clarity*



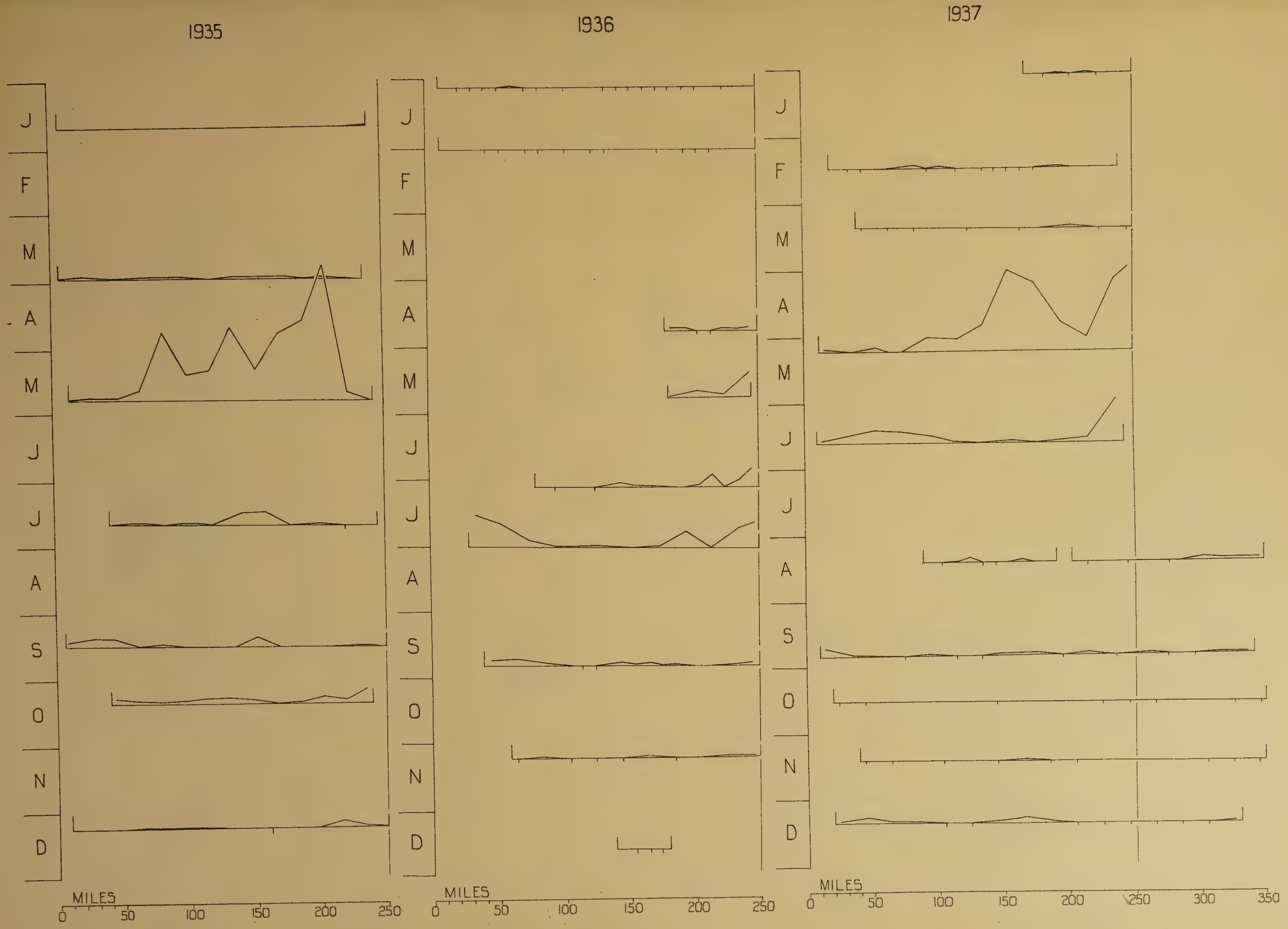
Records of ***TEMORA LONGICORNIS*** *on the* Bremen *line,* 1935 — 1937, *arranged as on Plate LXVIII.*

PLATE LXXXI



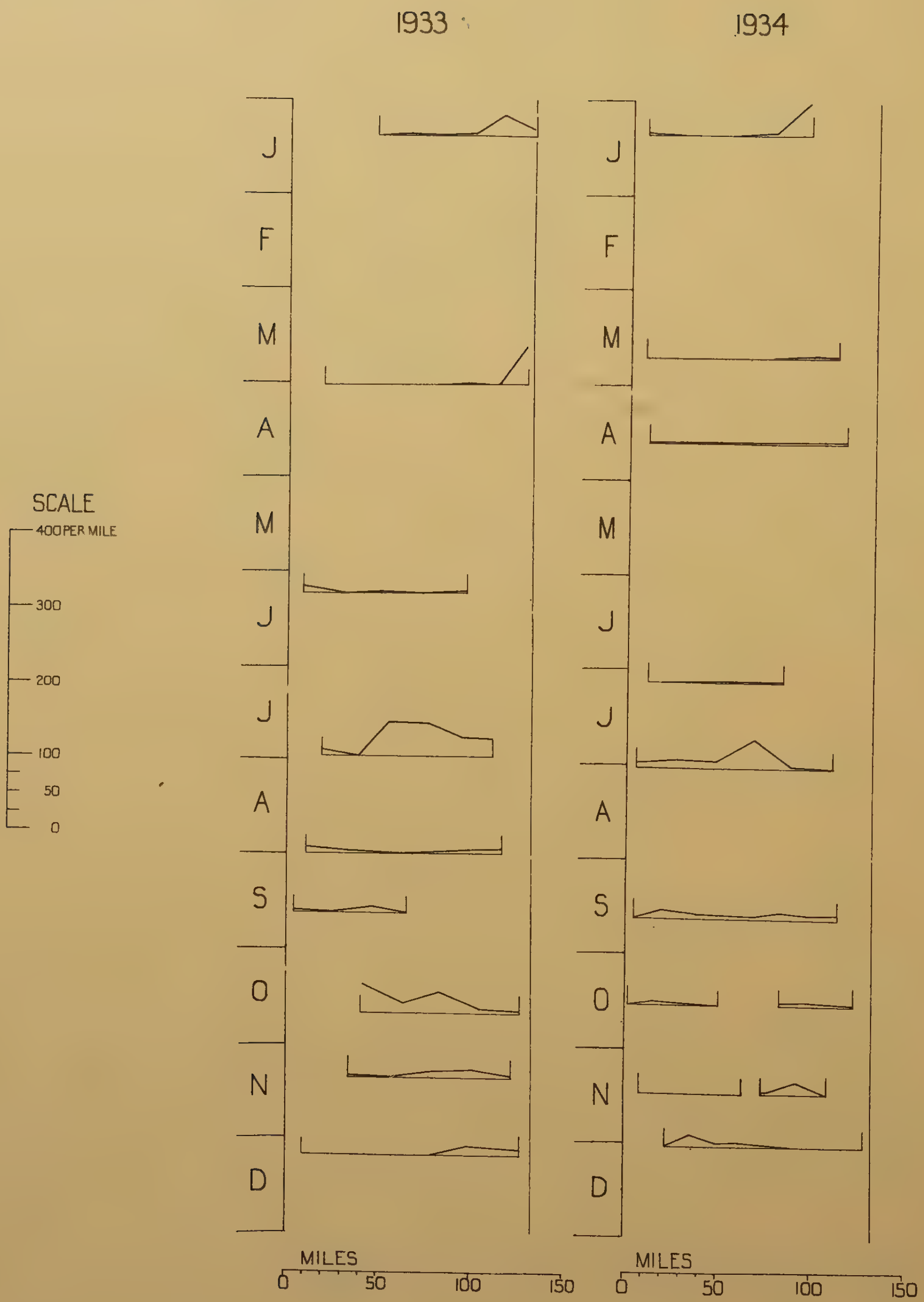
Records of **TEMORA LONGICORNIS** on the Copenhagen line, 1933 and 1934, arranged as on Plate LXIX.

PLATE LXXXII

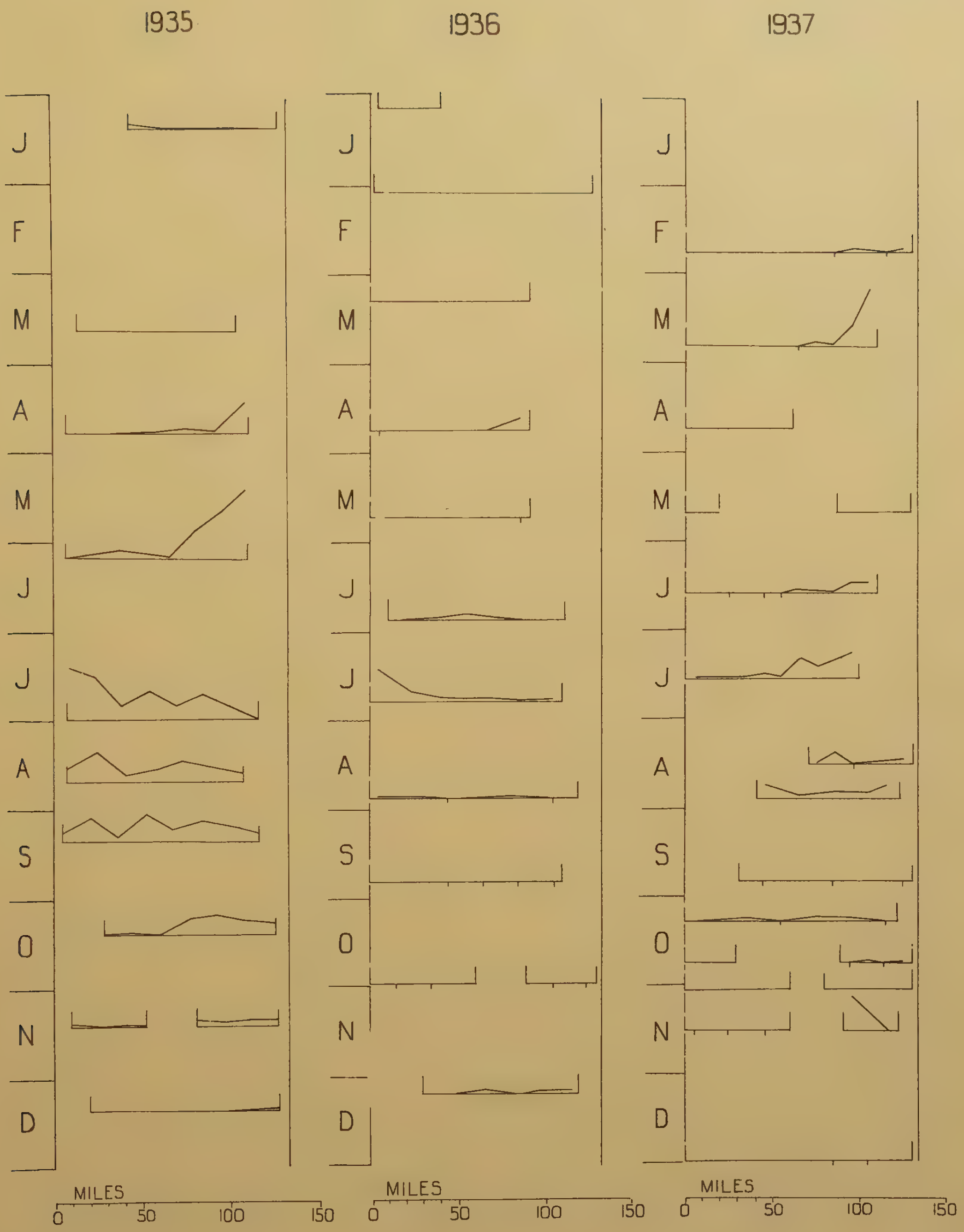


Records of **TEMORA LONGICORNIS** on the Copenhagen *line* 1935 – 1937 *arranged as on Plate LXX.*

PLATE LXXXIII

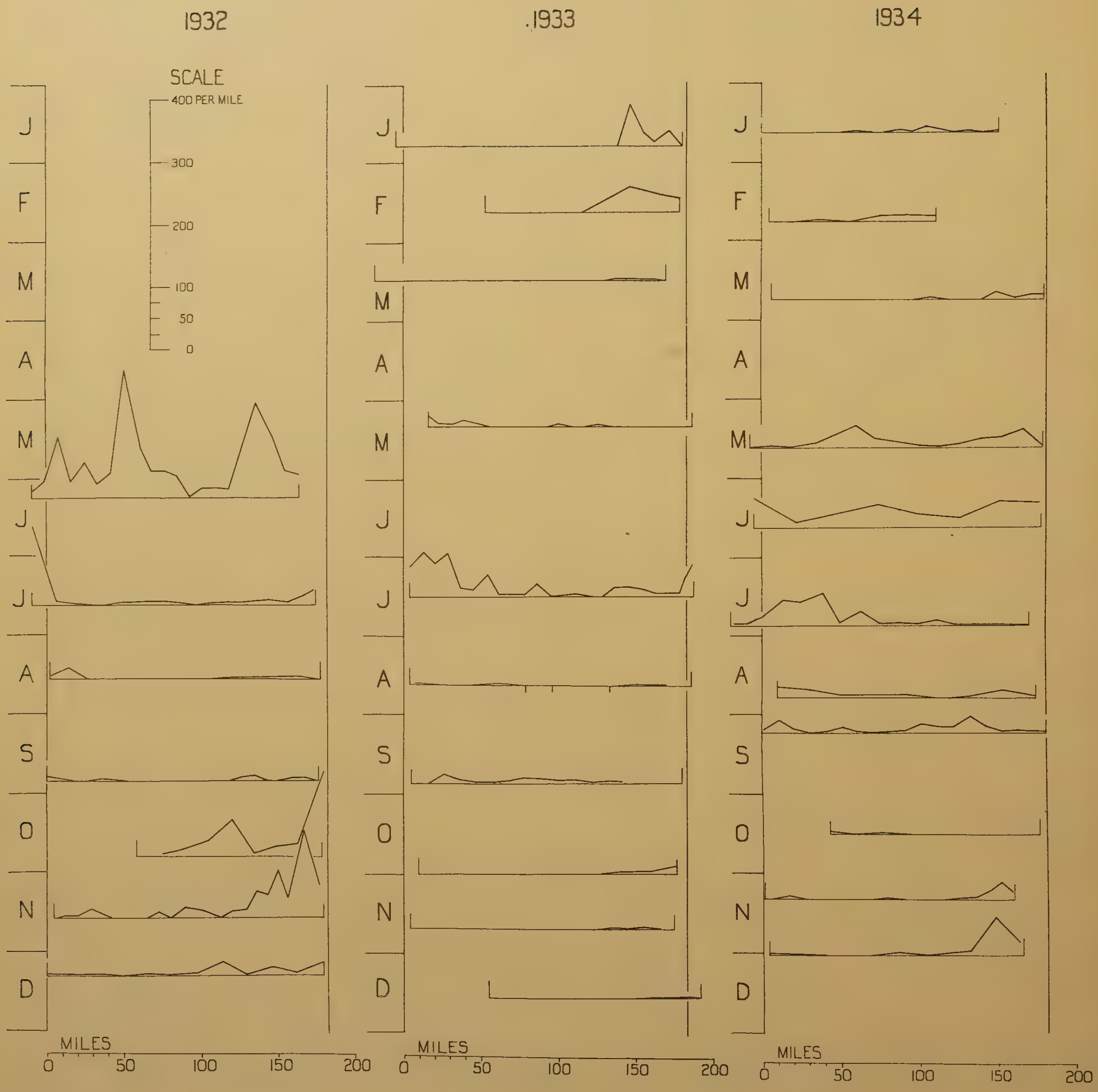


Records of **ACARTIA** *on the* Rotterdam *line,* 1933 *and* 1934, *arranged as on Plate LXV.*

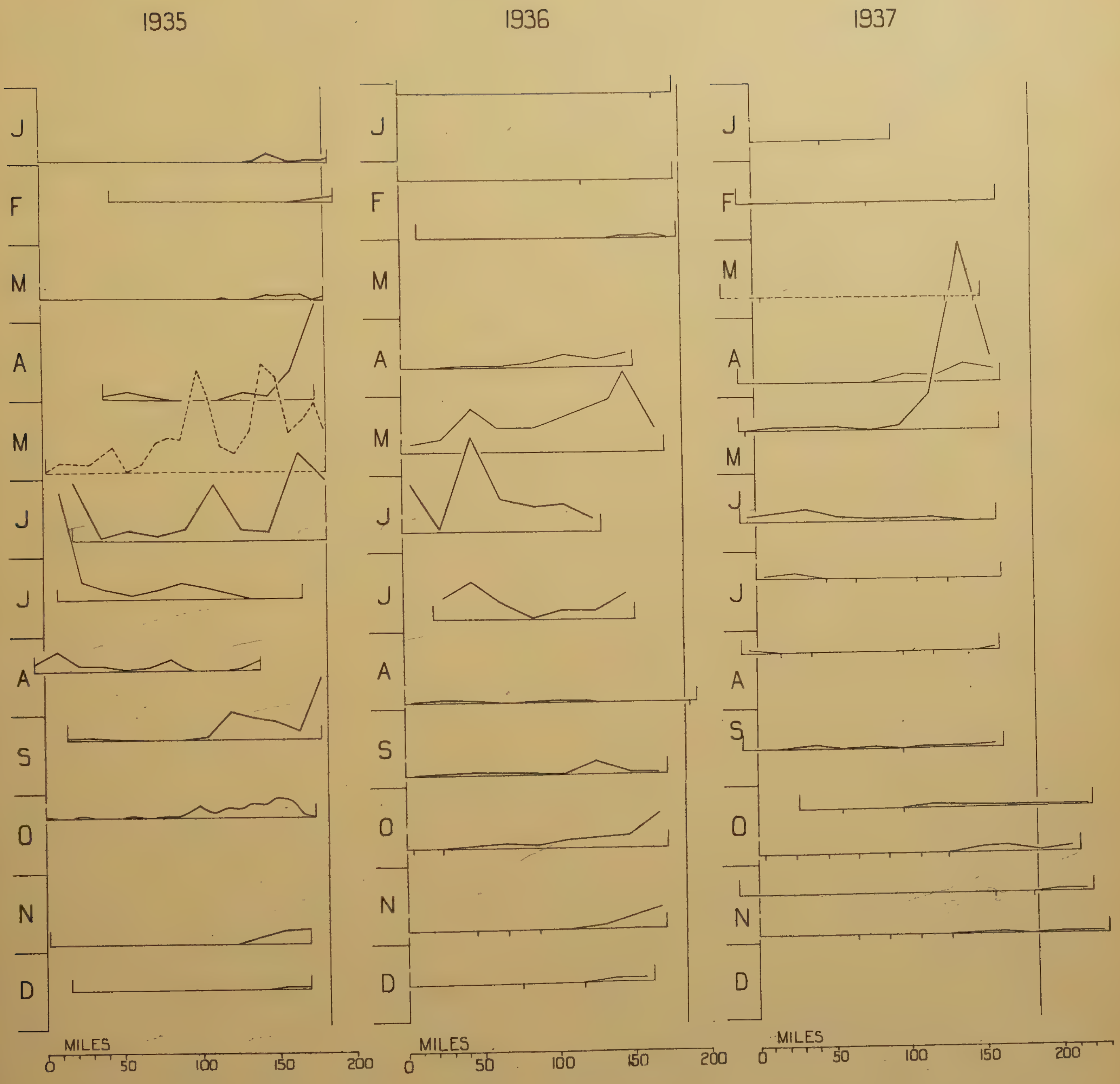


Records of **ACARTIA** *on the* Rotterdam *line.* 1935 — 1937, *arranged as on Plate LXVI.*

PLATE LXXXV

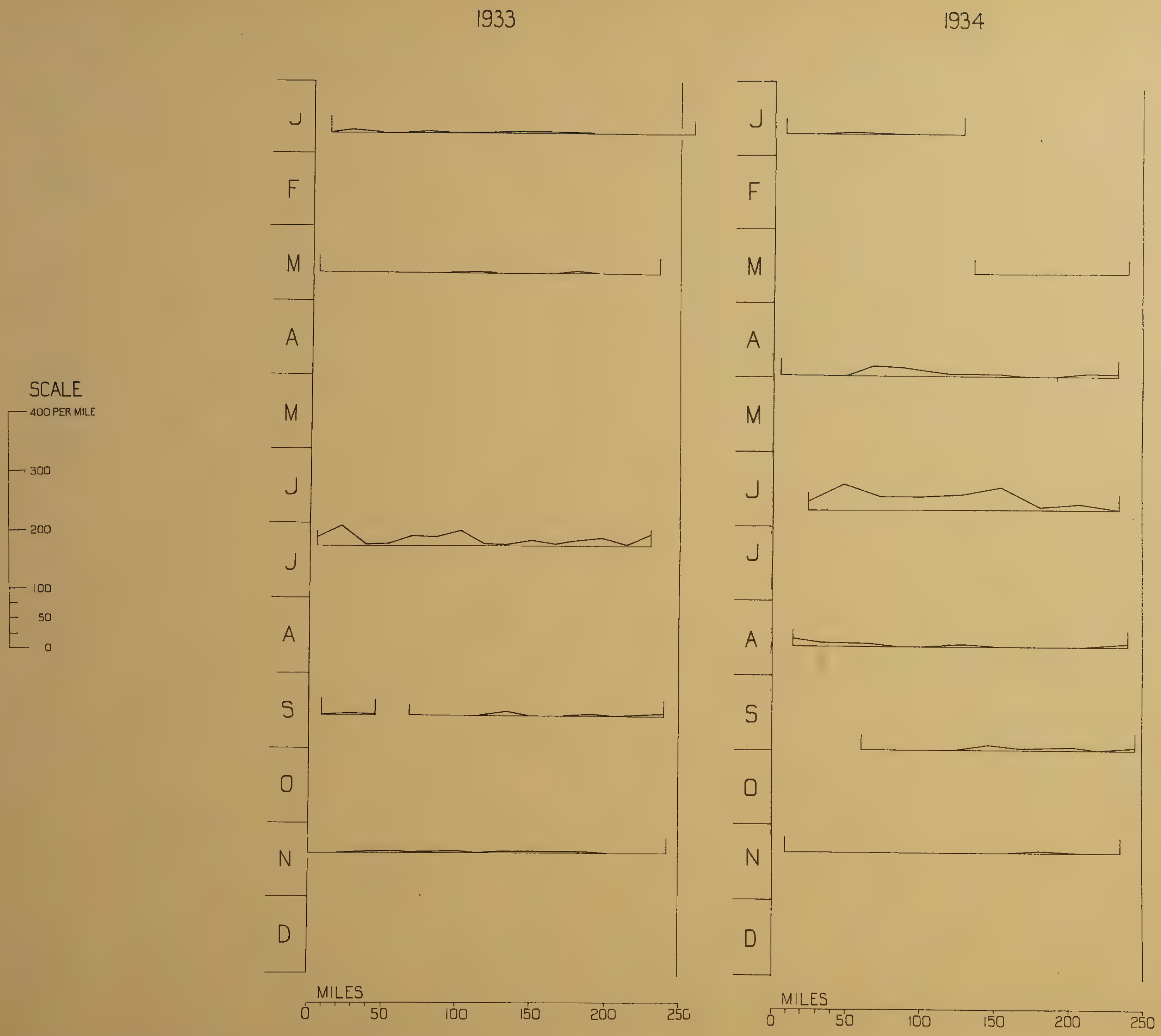


Records of **ACARTIA** *on the* Bremen *line,* 1932–1934, *arranged as on Plate LXVII.*

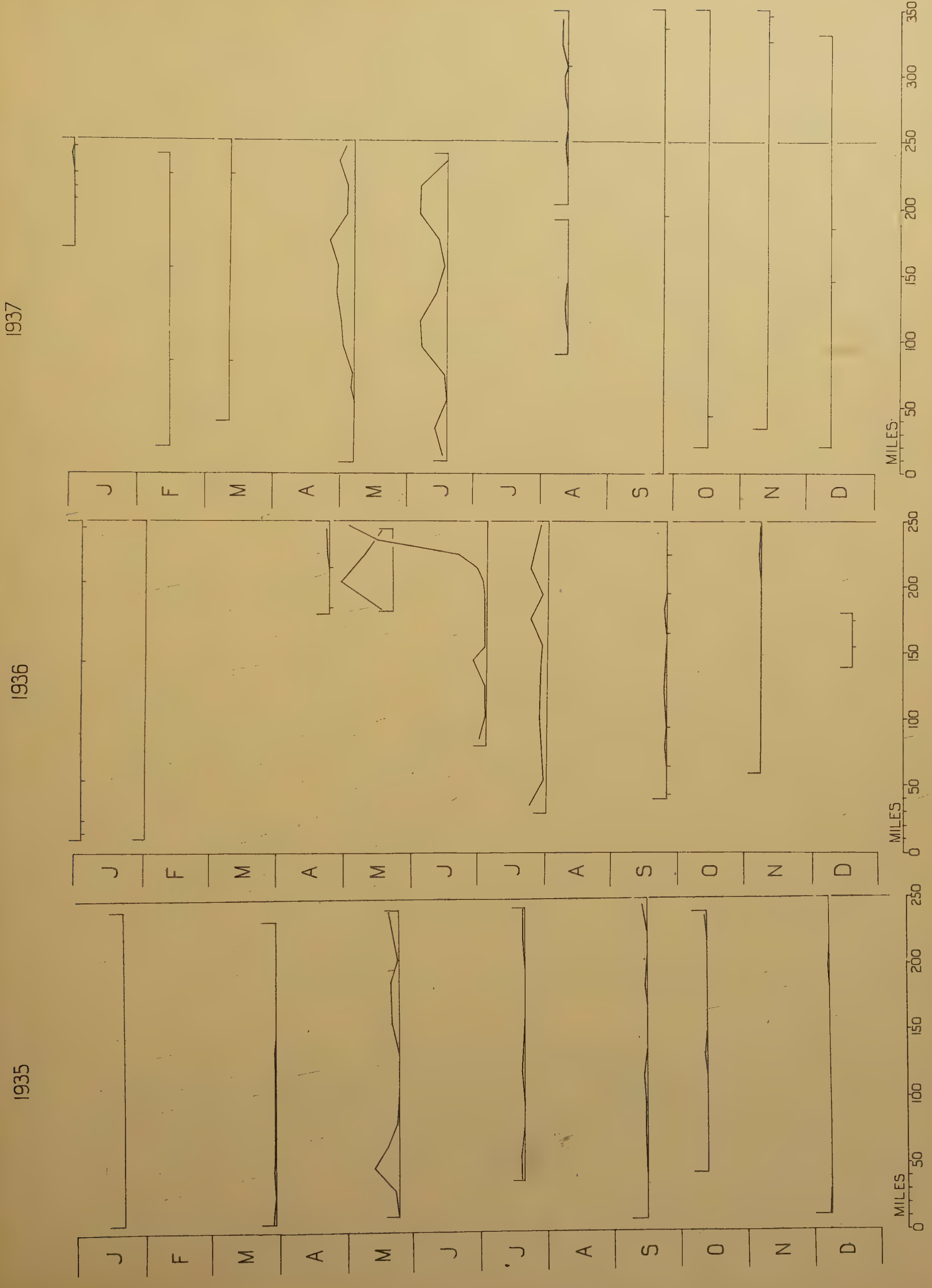


Records of **ACARTIA** *on the* Bremem *line,* 1935-1937, *arranged as on Plate LXVIII.*

PLATE LXXXVII

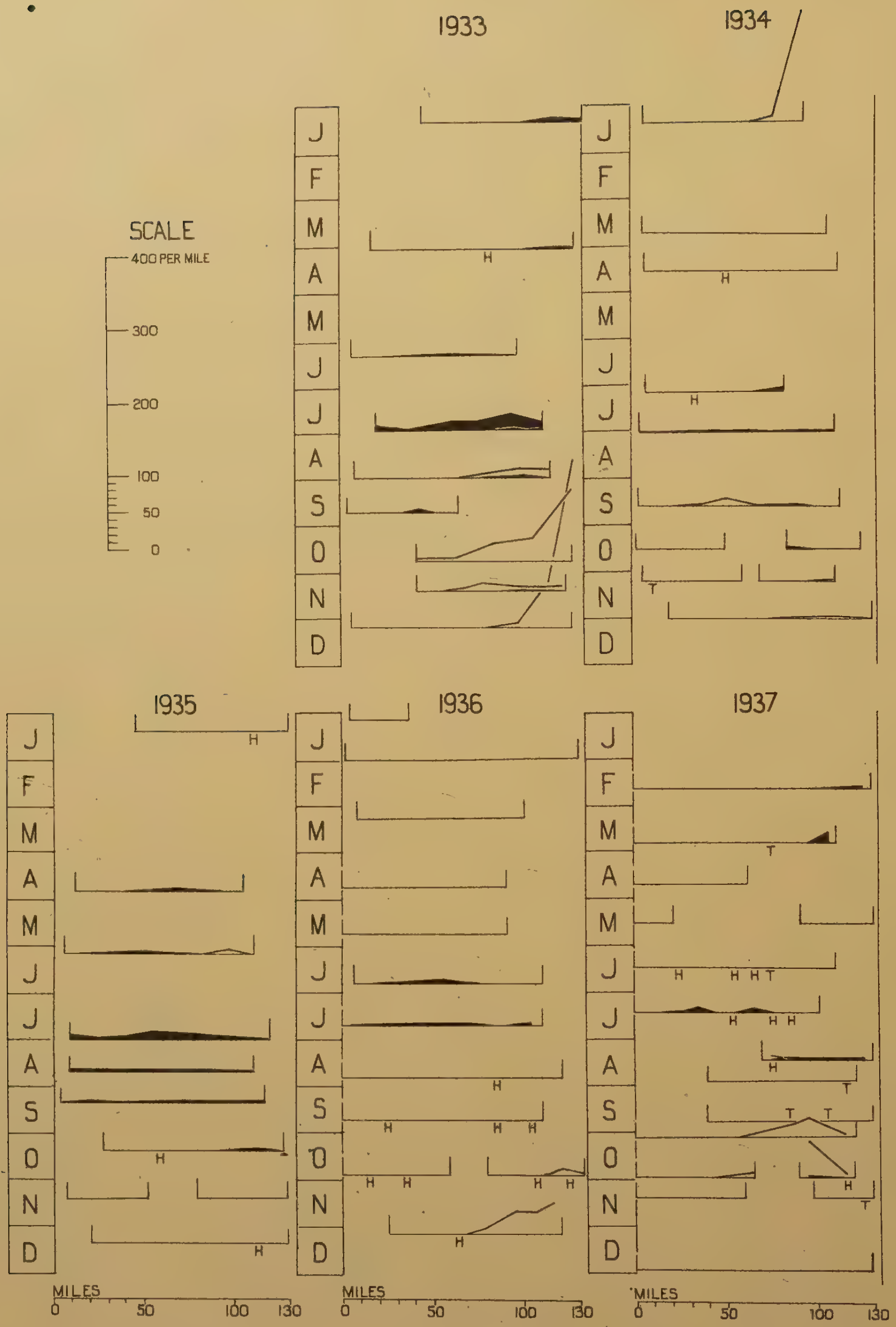


Records of **ACARTIA** on the Copenhagen *line*, 1933 *and* 1934, *arranged as on Plate LXIX.*

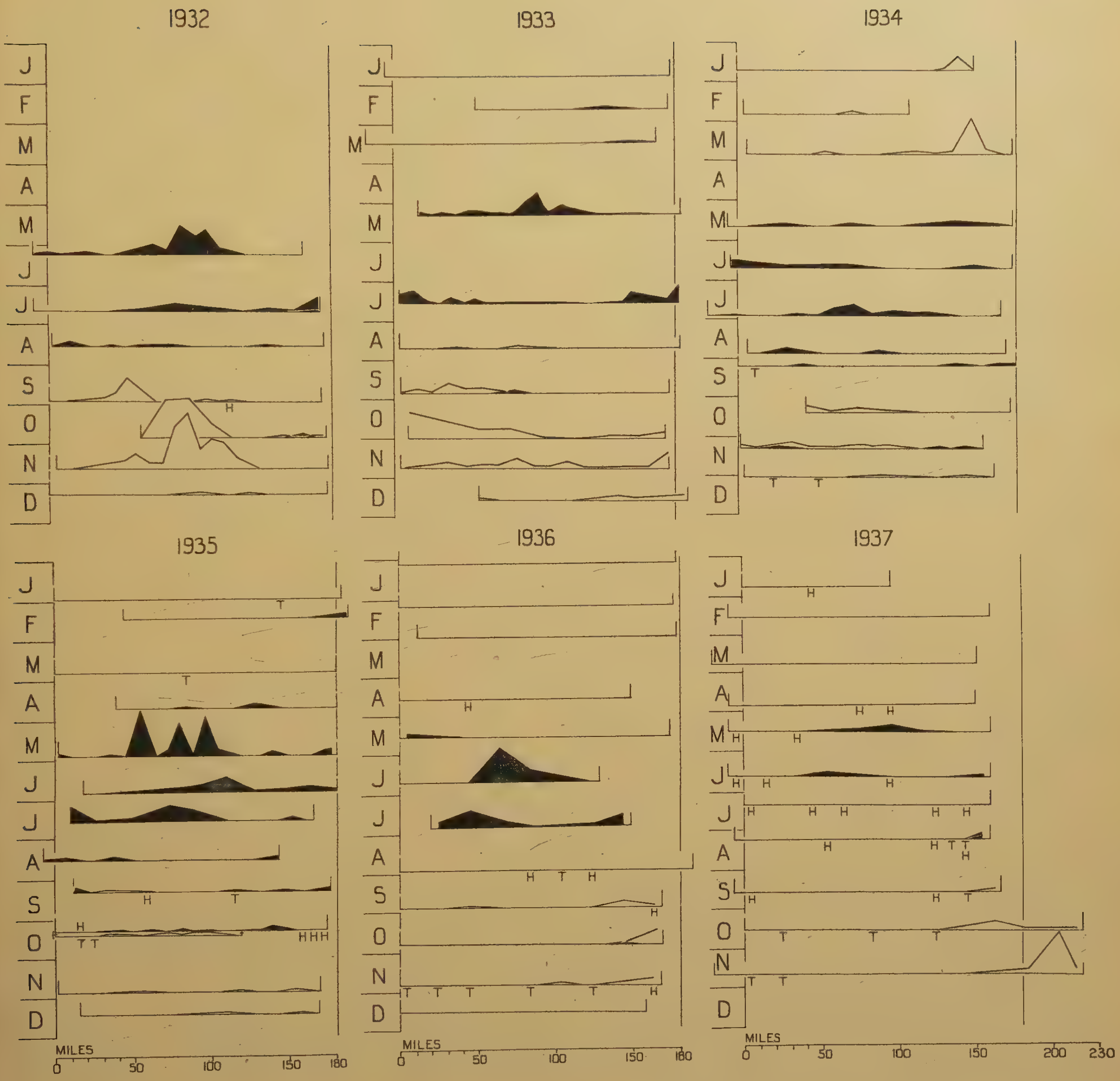


Records of ACARTIA *on the Copenhagen line, 1935 – 1937, arranged as on Plate LXX.*

PLATE LXXXIX

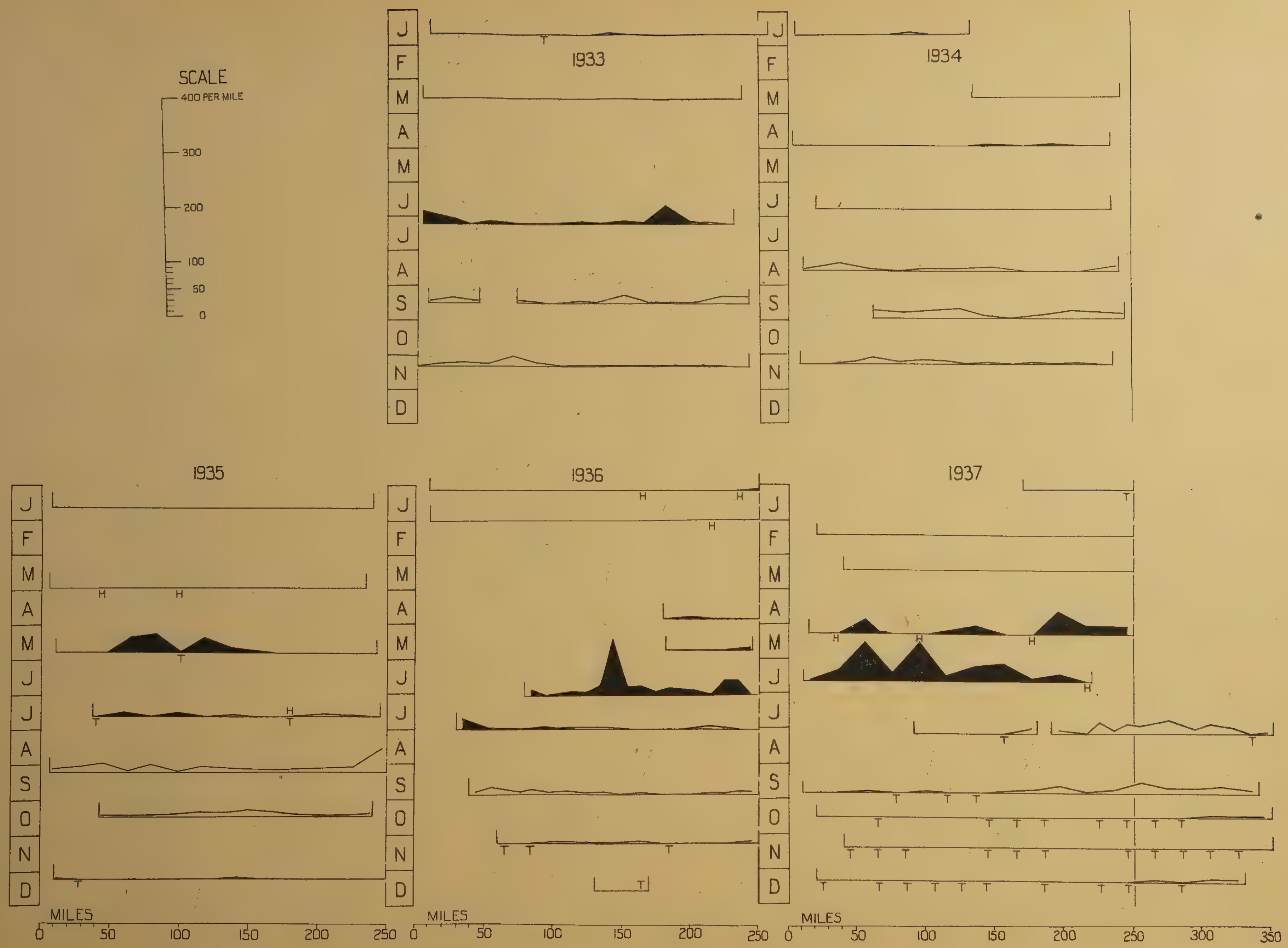


Records of **CENTROPAGES HAMATUS** *(blacked-in graphs) and* **C. TYPICUS** *(open line) on the* Rotterdam *line,* 1933 – 1937. *General arrangement as on Plates LXV and LXVI, but with time scale halved. Traces shown as 'H' and 'T' respectively.*



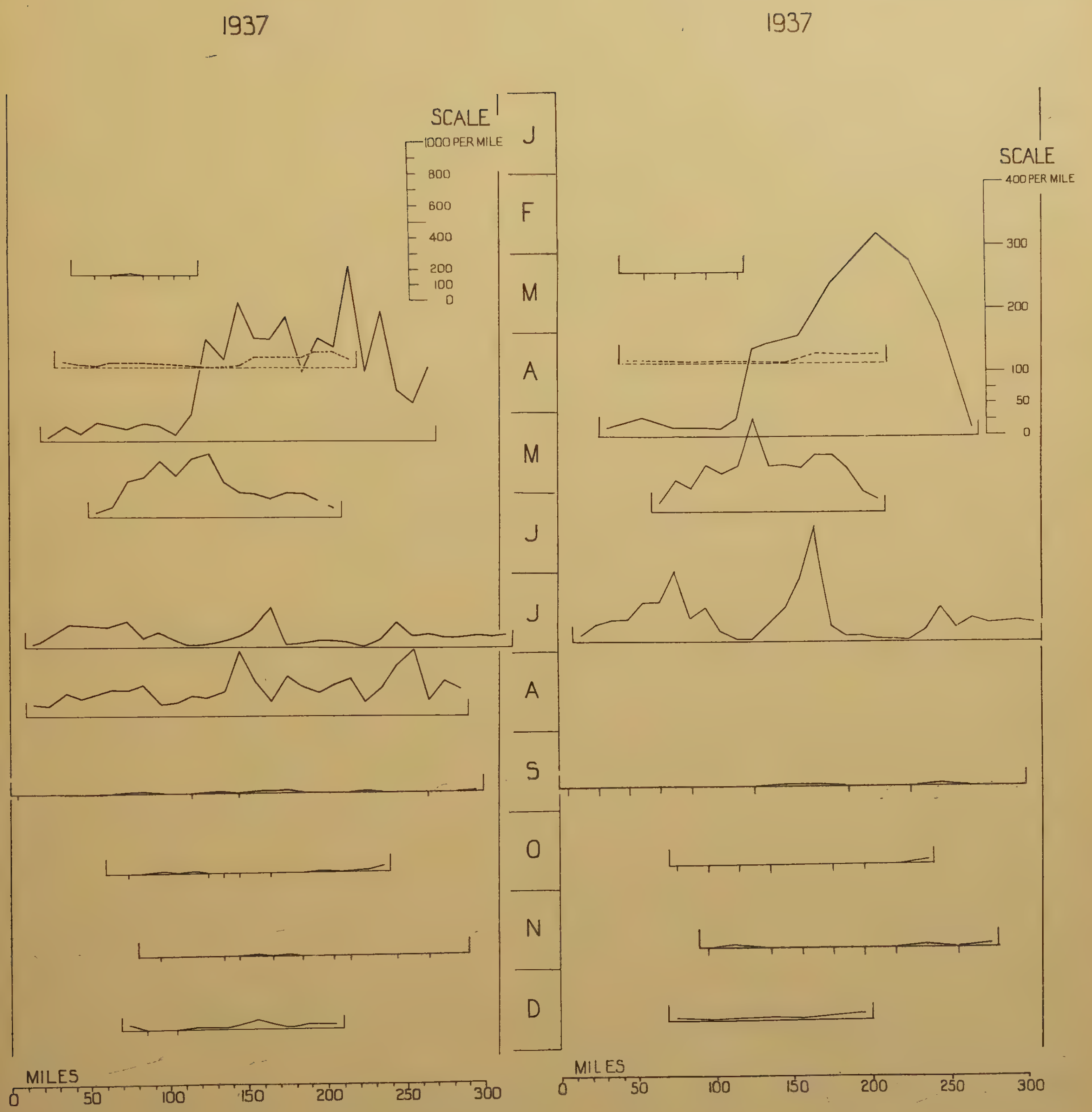
Records of ***CENTROPAGES HAMATUS*** *(blacked-in graphs) and* ***C. TYPICUS*** *(open line) on the* Bremen *line,* 1932—1937, *arranged as in Plates LXVII and LXVIII. Traces shown as 'H' and 'T' respectively. Scale as on Plate LXXXIX.*

PLATE XCI



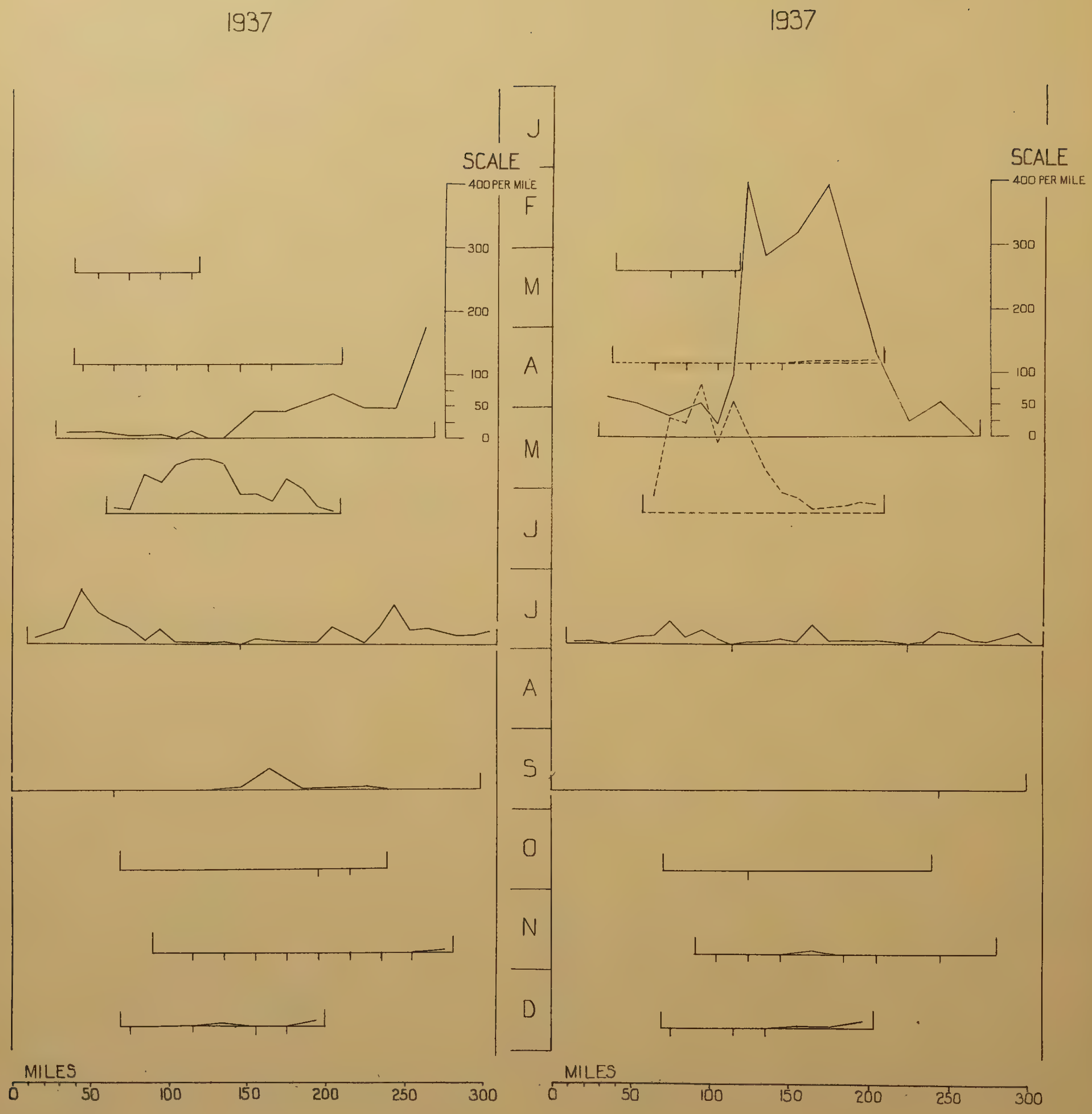
Records of **CENTROPAGES HAMATUS** *(blacked-in graphs) and* **C. TYPICUS** *(open line) on the Copenhagen line, 1933 – 1937, arranged as in Plates LXIX and LXX, but with time scale halved. Traces shown as 'H' and 'T' respectively.*

PLATE XCII



Records of ***TOTAL COPEPODA*** *(left) and* ***PSEUDOCALANUS AND PARACALANUS COMBINED*** *(right) on the* Esbjerg *line in* 1937. *General arrangement as described in Plate LXV, except that the vertical lines to left and right represent the positions of the* Sunk *and* Graadyb *lightvessels. Overlapping graphs may be shown in broken line for clarity.*

PLATE XCIII



Records of **TEMORA LONGICORNIS** (left) and **ACARTIA** (right) on the Esbjerg line in 1937. General arrangements as described in Plate LXV except that the vertical lines to left and right represent the positions of the Sunk and Graadyb lightvessels. Overlapping graphs may be shown in broken line for clarity.

PLATES XCIV–CXXV

MAPS SHOWING THE MONTHLY
DISTRIBUTION OF THE
TOTAL COPEPODA,
CENTROPAGES HAMATUS,
CENTROPAGES TYPICUS,
ISIAS CLAVIPES AND
CORYCAEUS ANGLICUS,
IN THE SOUTHERN NORTH SEA
JUNE 1932 TO DECEMBER 1937

PLATE XCIV

The following Explanation relates to
PLATES XCIV-CVI

This series of maps has been prepared to show the distribution of the ***TOTAL COPEPODA*** in the southern North Sea month by month from June 1932 to December 1937.

As on previous plates the estimated numbers per mile are shown as graphs above the base line and by short vertical strokes below.

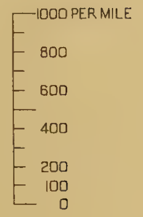
The date of each record is shown below its eastern end.

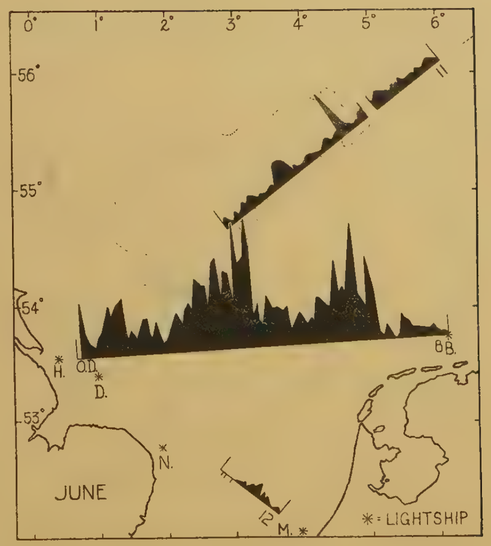
The letters H. OD. D. N. M and B indicate the positions of the **HUMBER, OUTER DOWSING, EAST DUDGEON, NEWARP, MAAS** and **BORKUM** lightvessels respectively.

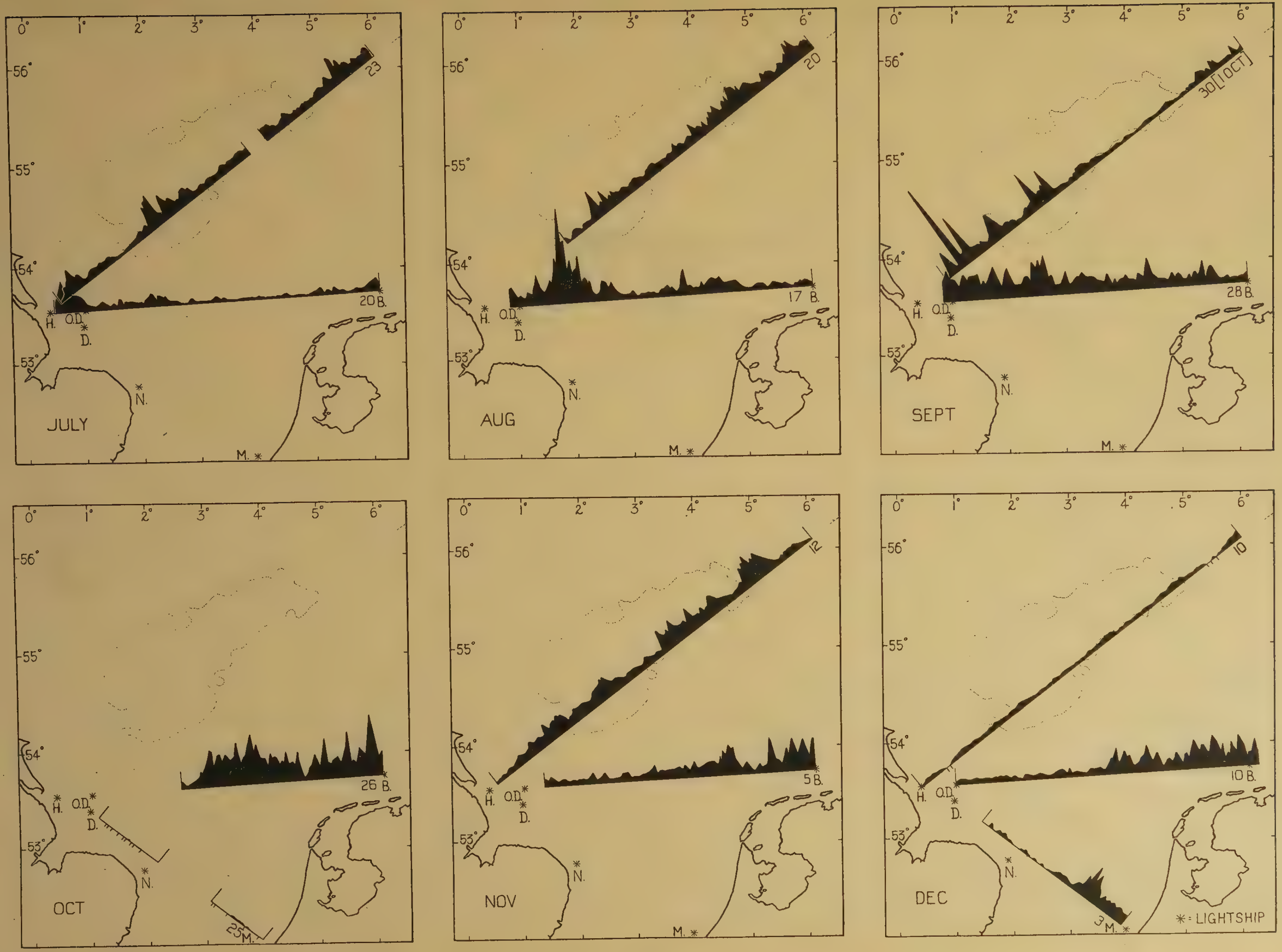
The 20 fathom contour of the **DOGGER BANK** is marked by a faint dotted line.

The first records for June 1932 are shown in the map on the right.

Scale for
Plates XCIV-CVI:

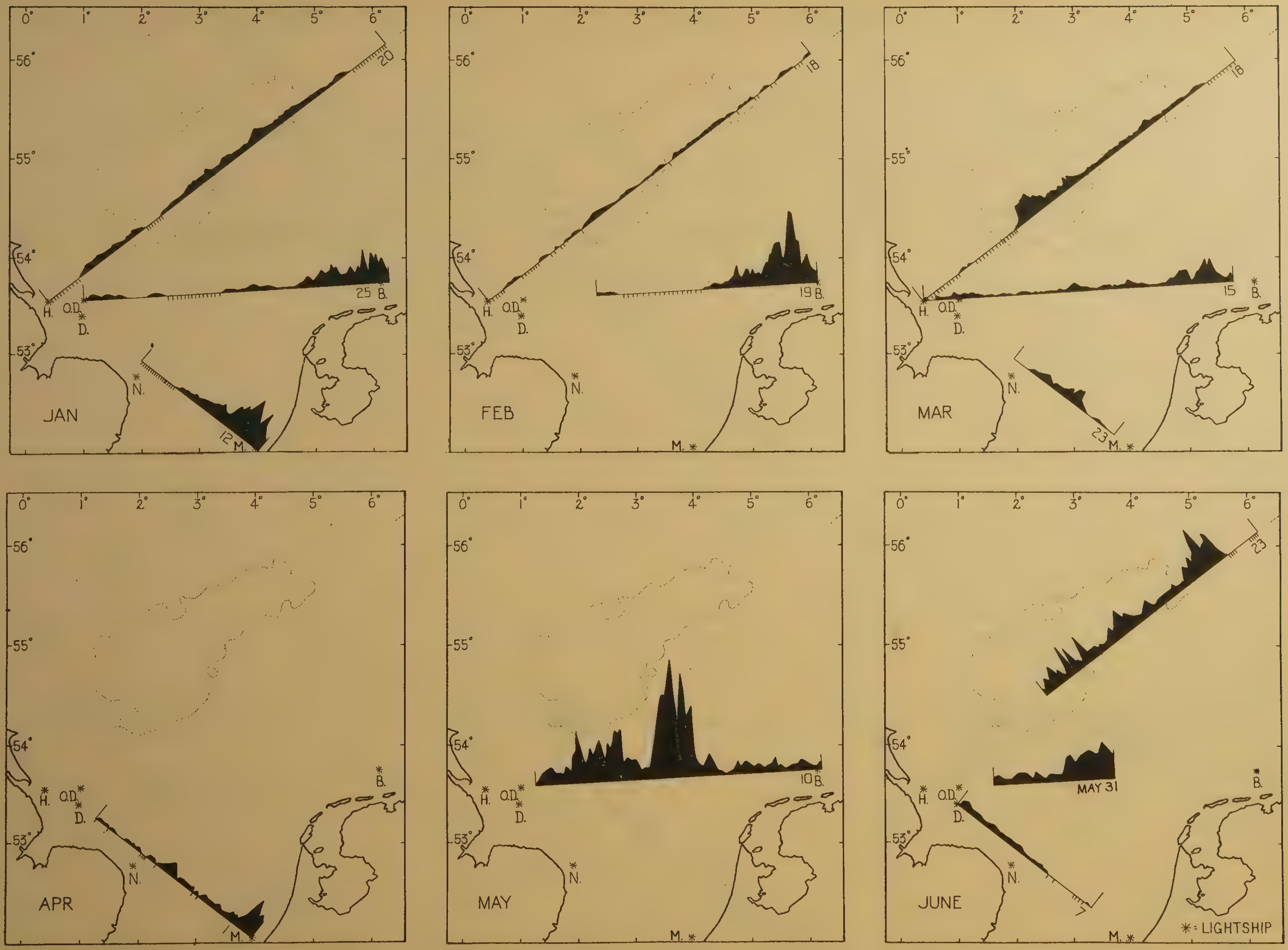





JULY
AUG
SEPT
OCT
NOV
DEC
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
23
20 B.
20
17 B.
30 [1 OCT]
28 B.
26 B.
25 M.
12
5 B.
10
10 B.
3 M.
✳ = LIGHTSHIP

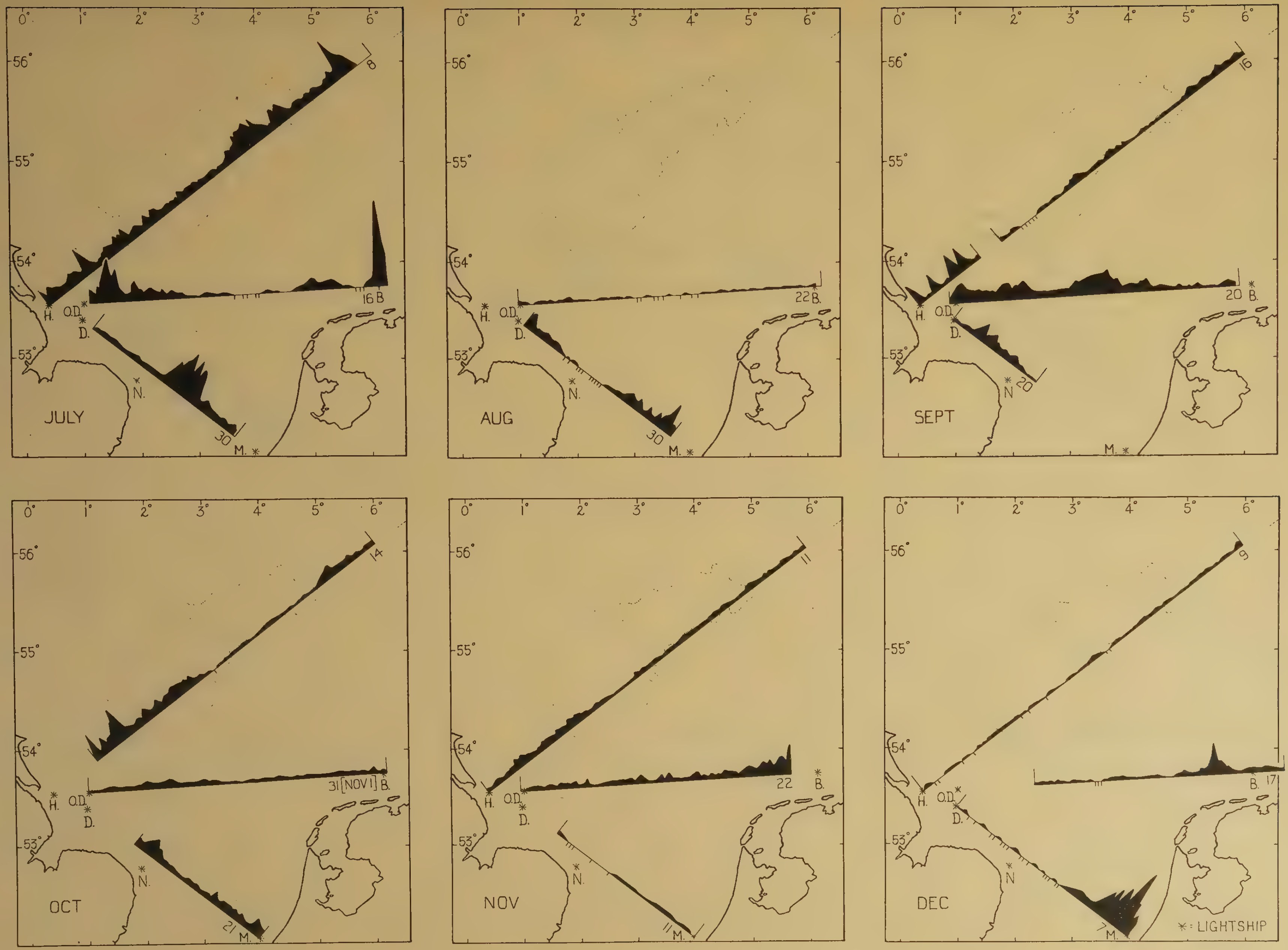
TOTAL COPEPODA, *July – December, 1932.* *For further explanation see Plate XCIV.*

PLATE XCVI


JAN
FEB
MAR
APR
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
20
25
12
18
19
16
15
23
10
MAY 31
* = LIGHTSHIP

TOTAL COPEPODA. *January – June. 1933. For further explanation see Plate XCIV.*

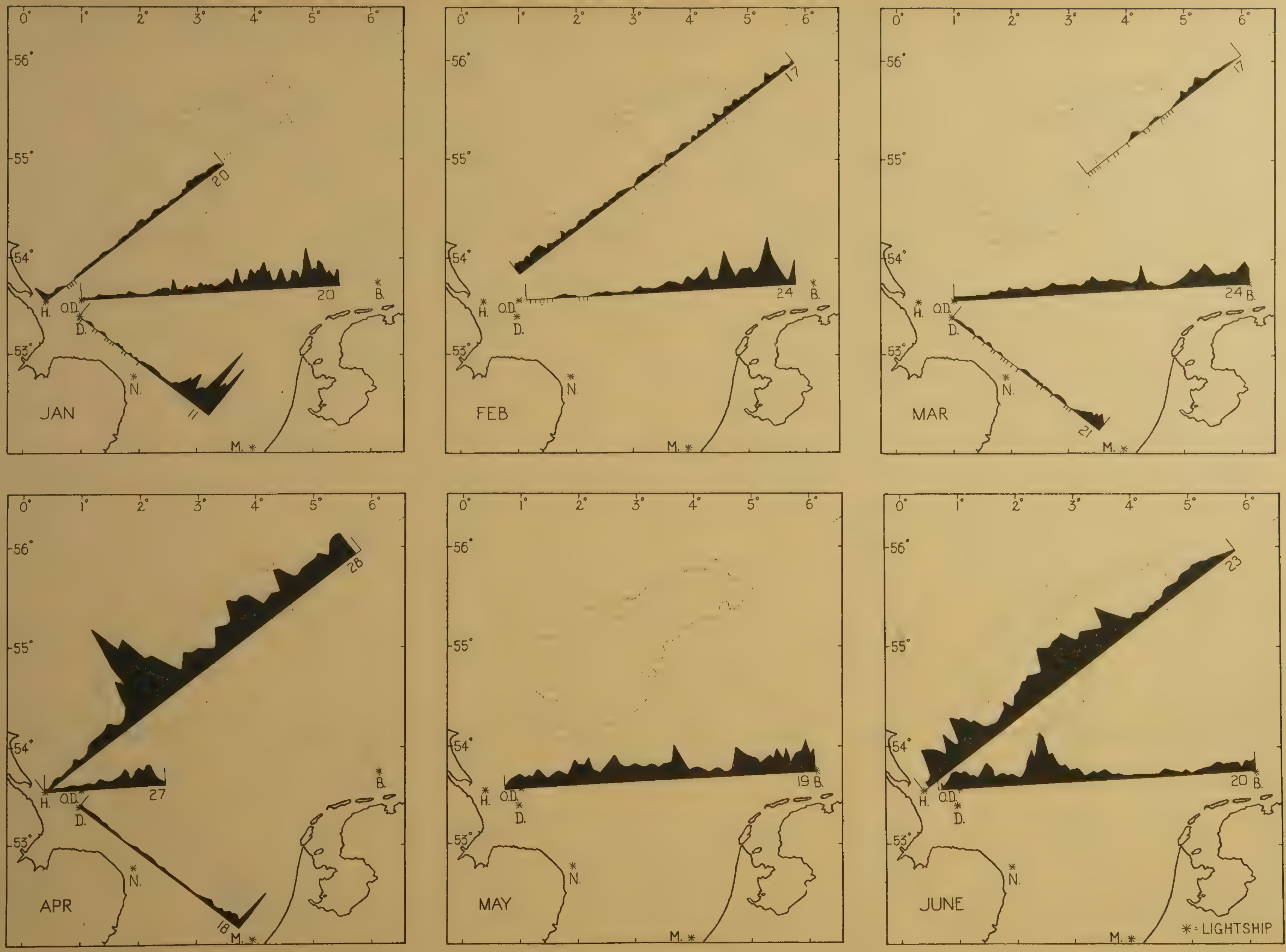
PLATE XCVII



JULY
AUG
SEPT
OCT
NOV
DEC
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
8
16 B
30 M.
22 B.
30 M.
16
20 B.
20
14
31 [NOV I] B.
21 M.
11
22
11 M.
9
B. 17
M.
✳ = LIGHTSHIP

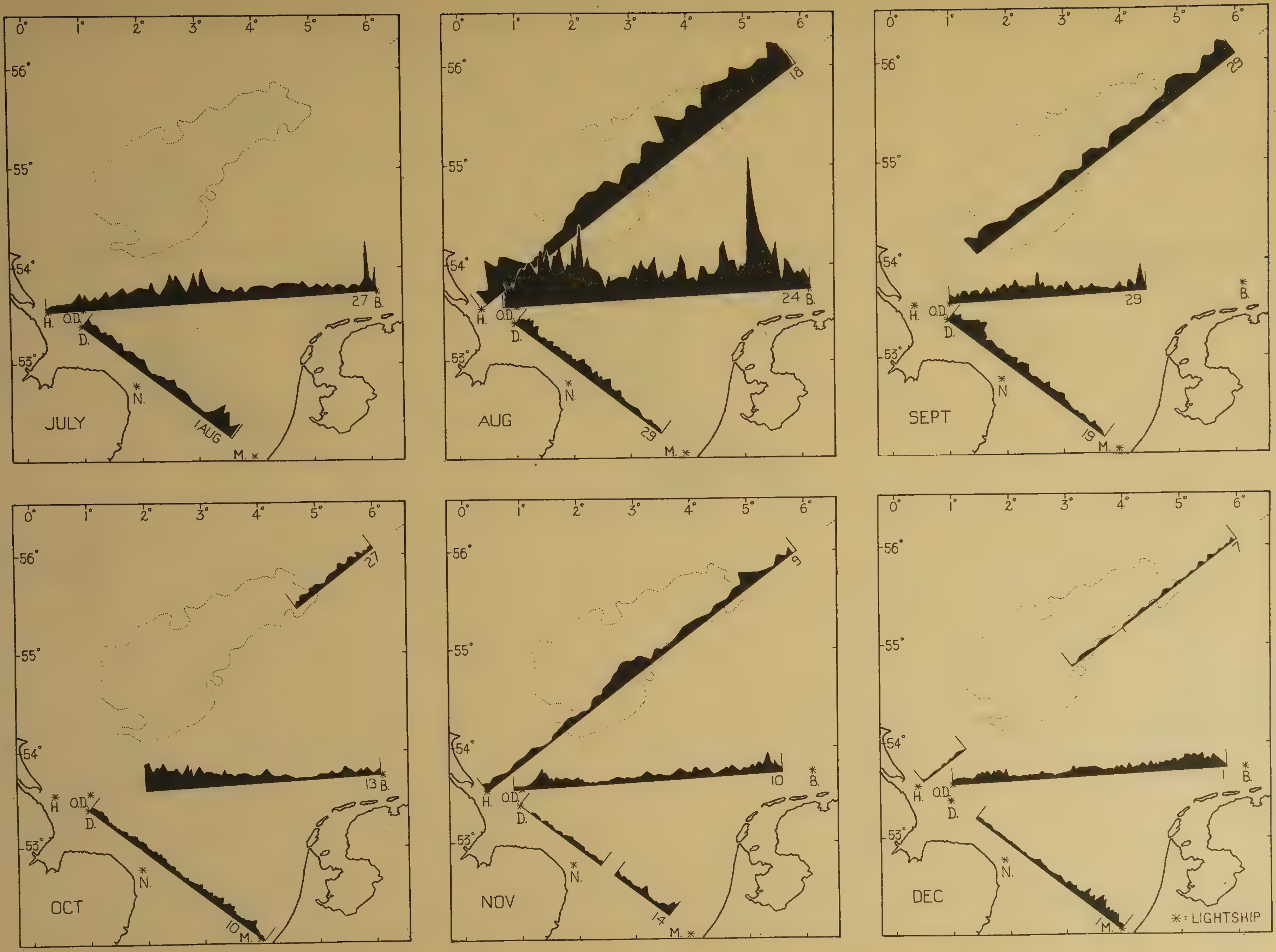
TOTAL COPEPODA. *July – December, 1933. For further explanation see Plate XCIV.*

PLATE XCVIII


JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
H.
O.D.
D.
N.
M.
B.
20
11
24
17
21
28
27
18
19
23
✱ = LIGHTSHIP

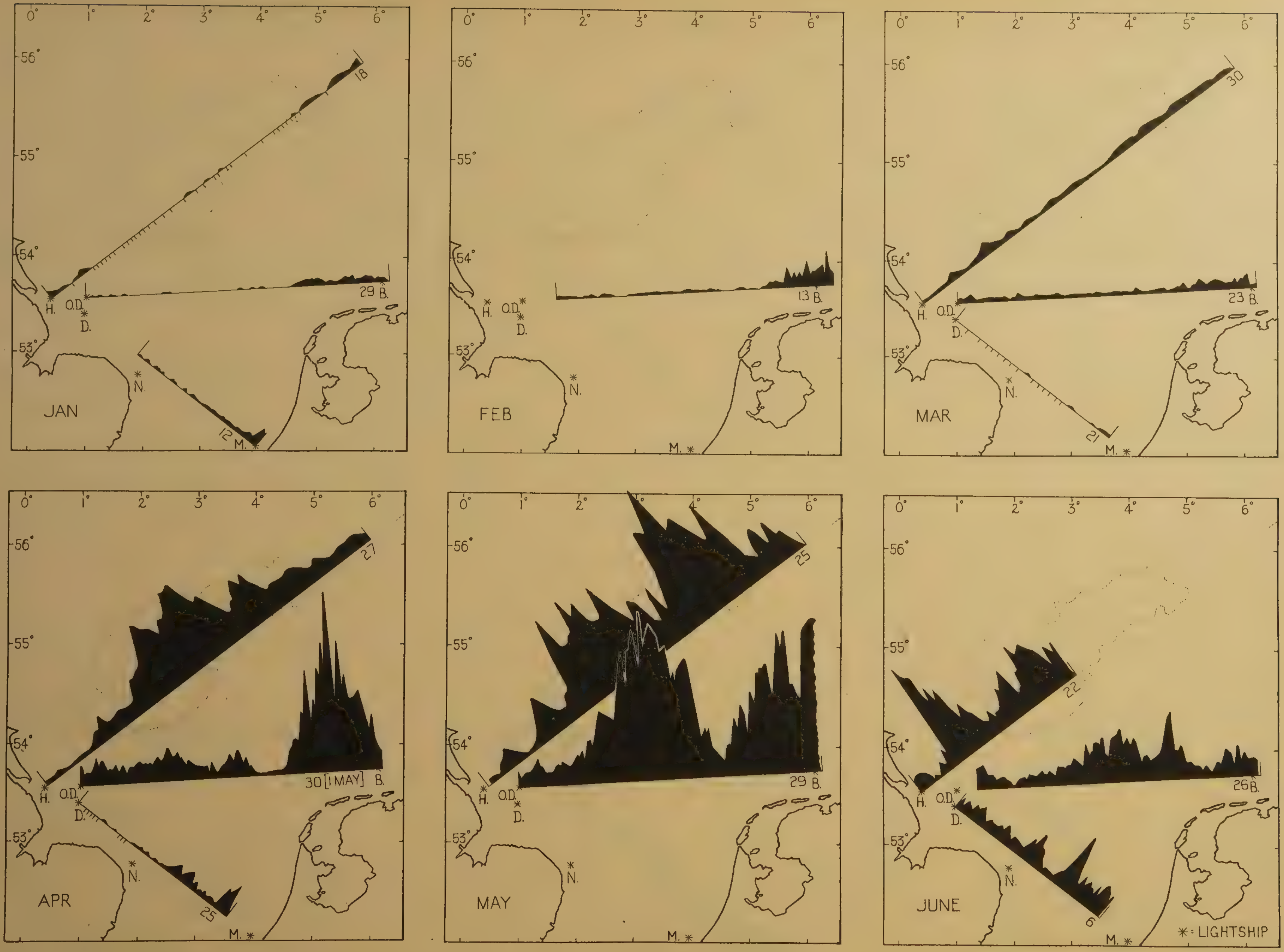
TOTAL COPEPODA. *January – June, 1934. For further explanation see Plate XCIV.*

PLATE XCIX

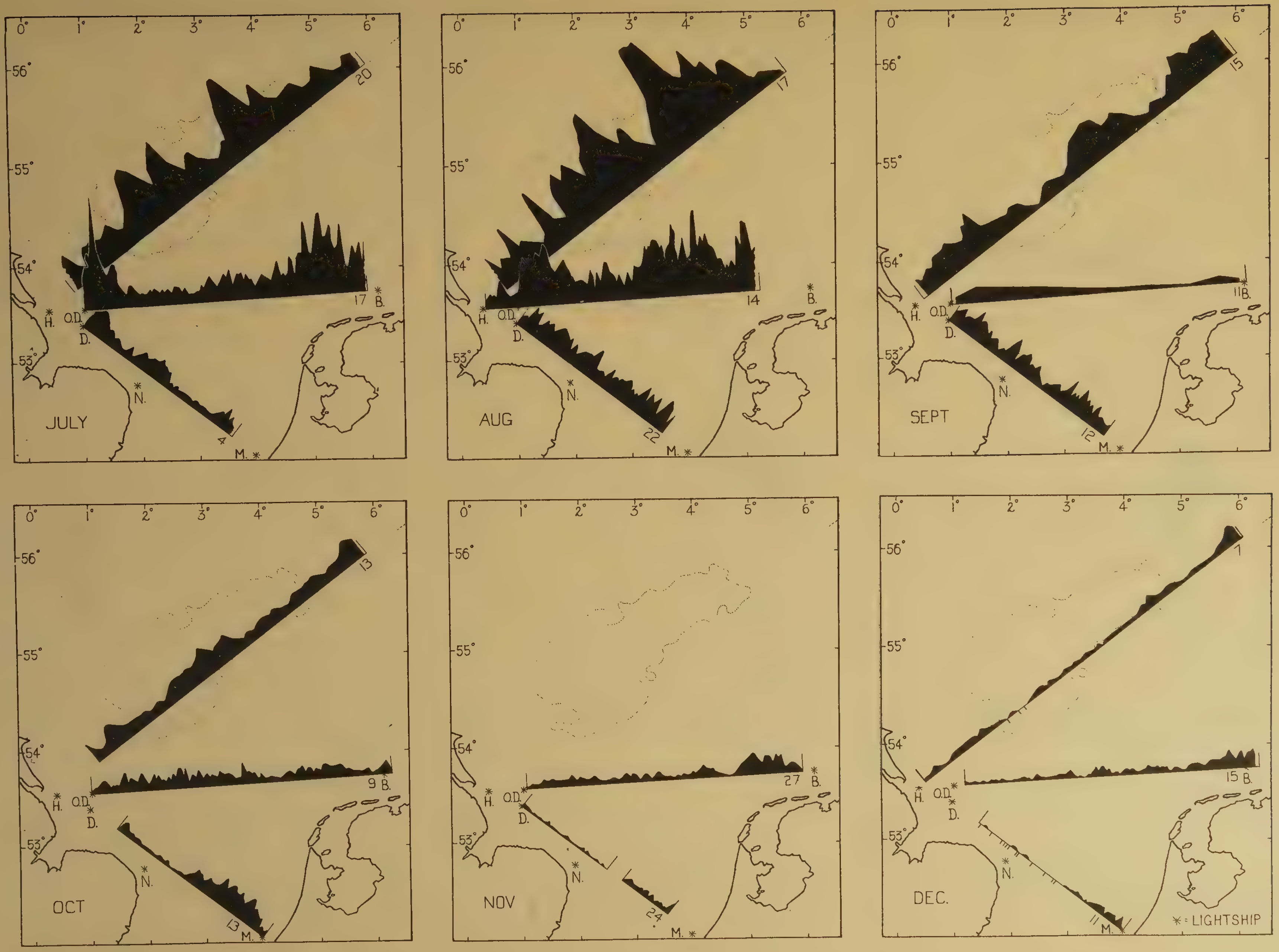

0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
JULY
27
1 AUG
AUG
18
24
29
SEPT
29
29
19
OCT
27
13
10
NOV
9
10
14
DEC
1
* = LIGHTSHIP

TOTAL COPEPODA, *July – December, 1934.* *For further explanation see Plate XCIV.*

PLATE C

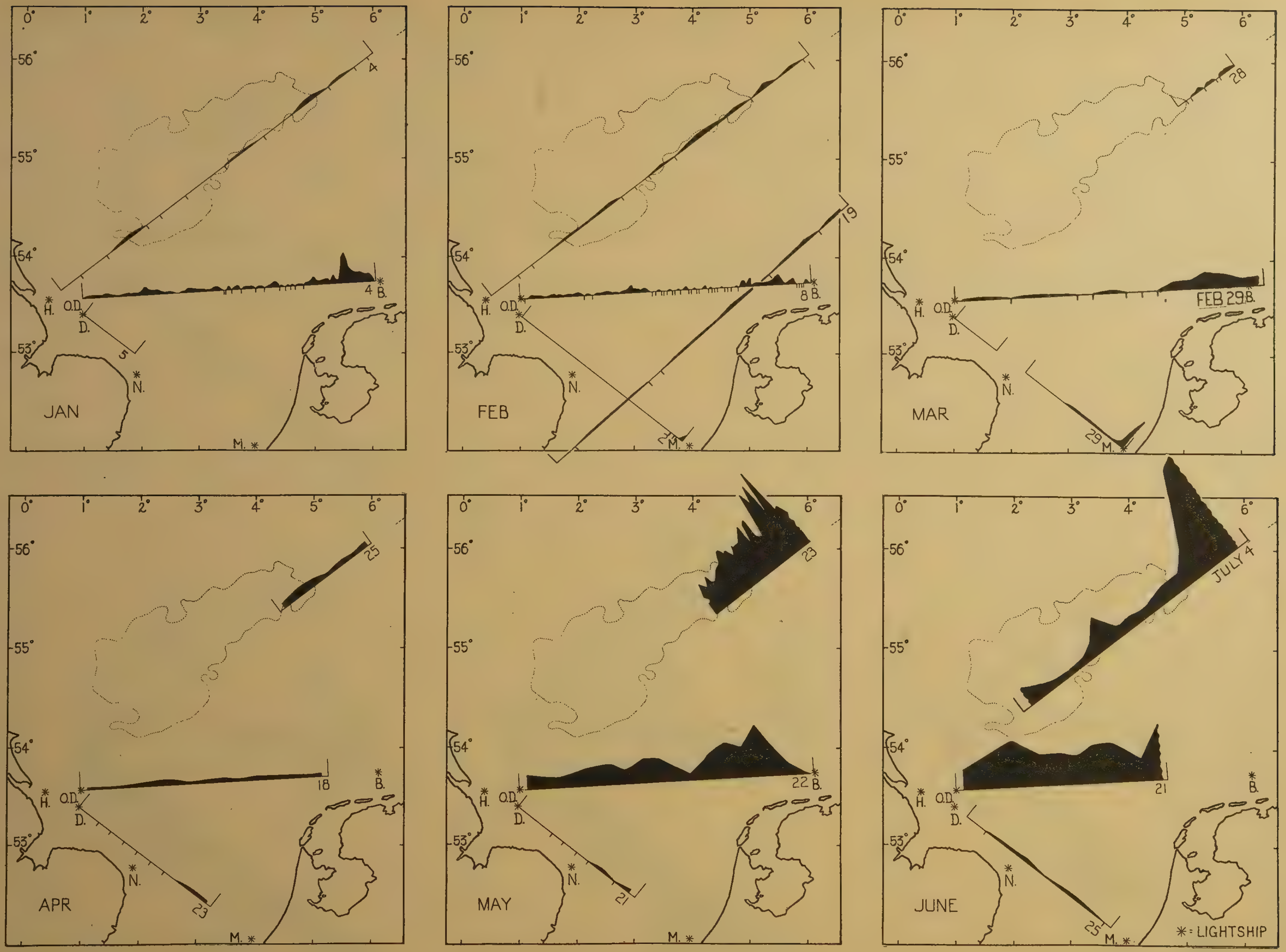

JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
18
29 B.
12 M.
13 B.
30
23 B.
21
27
30 [1 MAY] B.
25
29 B.
22
26 B.
6
✱ : LIGHTSHIP

TOTAL COPEPODA, *January – June, 1935. For further explanation see Plate XCIV.*


JULY
20
17
4
AUG
17
14
22
SEPT
15
11
12
OCT
13
9
13
NOV
27
24
DEC.
1
15
11
H.
O.D.
D.
N.
M.
B.
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
* = LIGHTSHIP

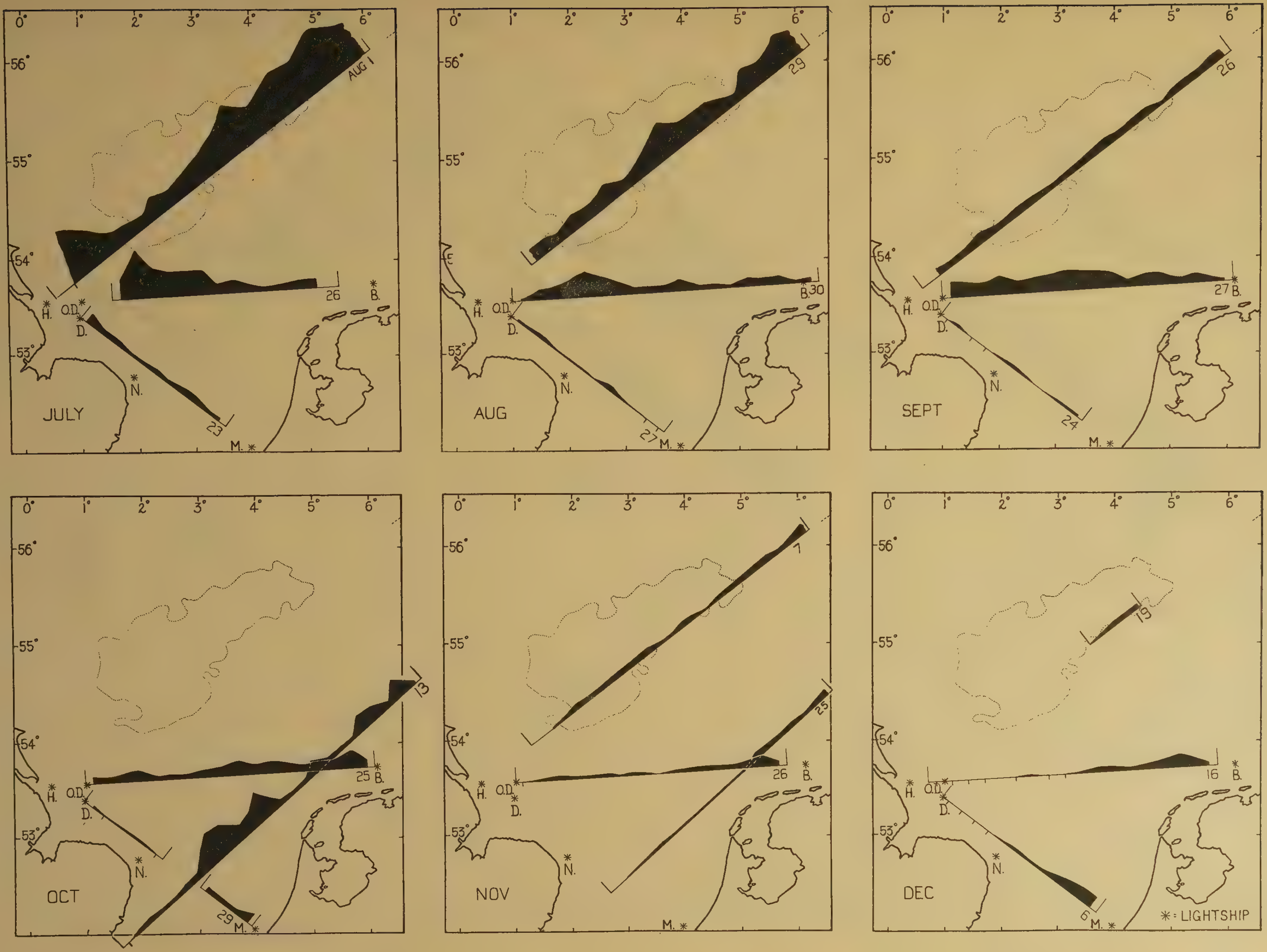
TOTAL COPEPODA. *July – December, 1935. For further explanation see Plate XCIV.*

PLATE CII


JAN
FEB
MAR
APR
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
4
5
4 B.
8 B.
19
2 M.
28
FEB 29 B.
29 M.
25
18
23
22 B.
21
JULY 4
25 M.
✻ = LIGHTSHIP

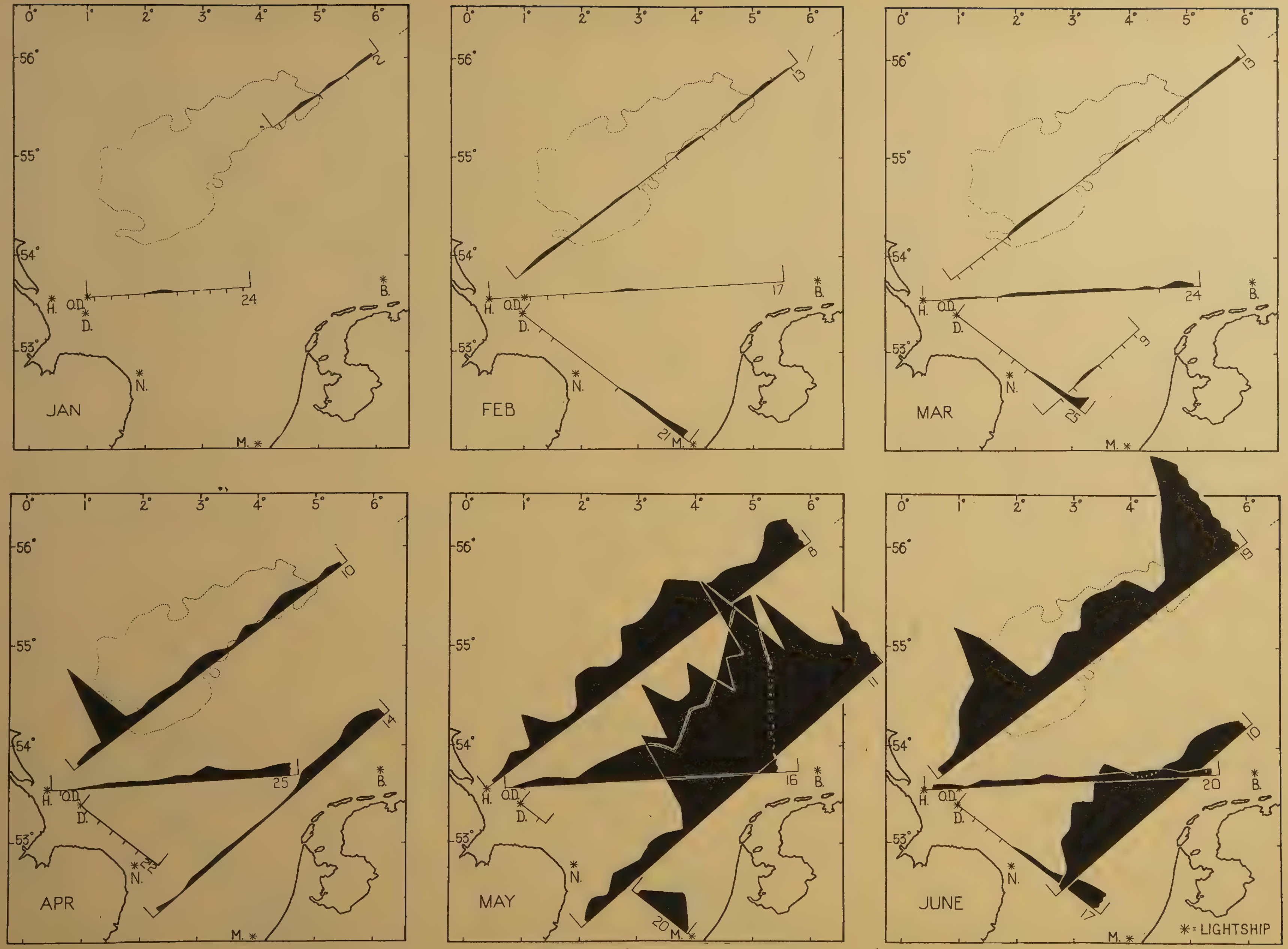
TOTAL COPEPODA, *January – June, 1936.* *For further explanation see Plate XCIV.*

PLATE CIII

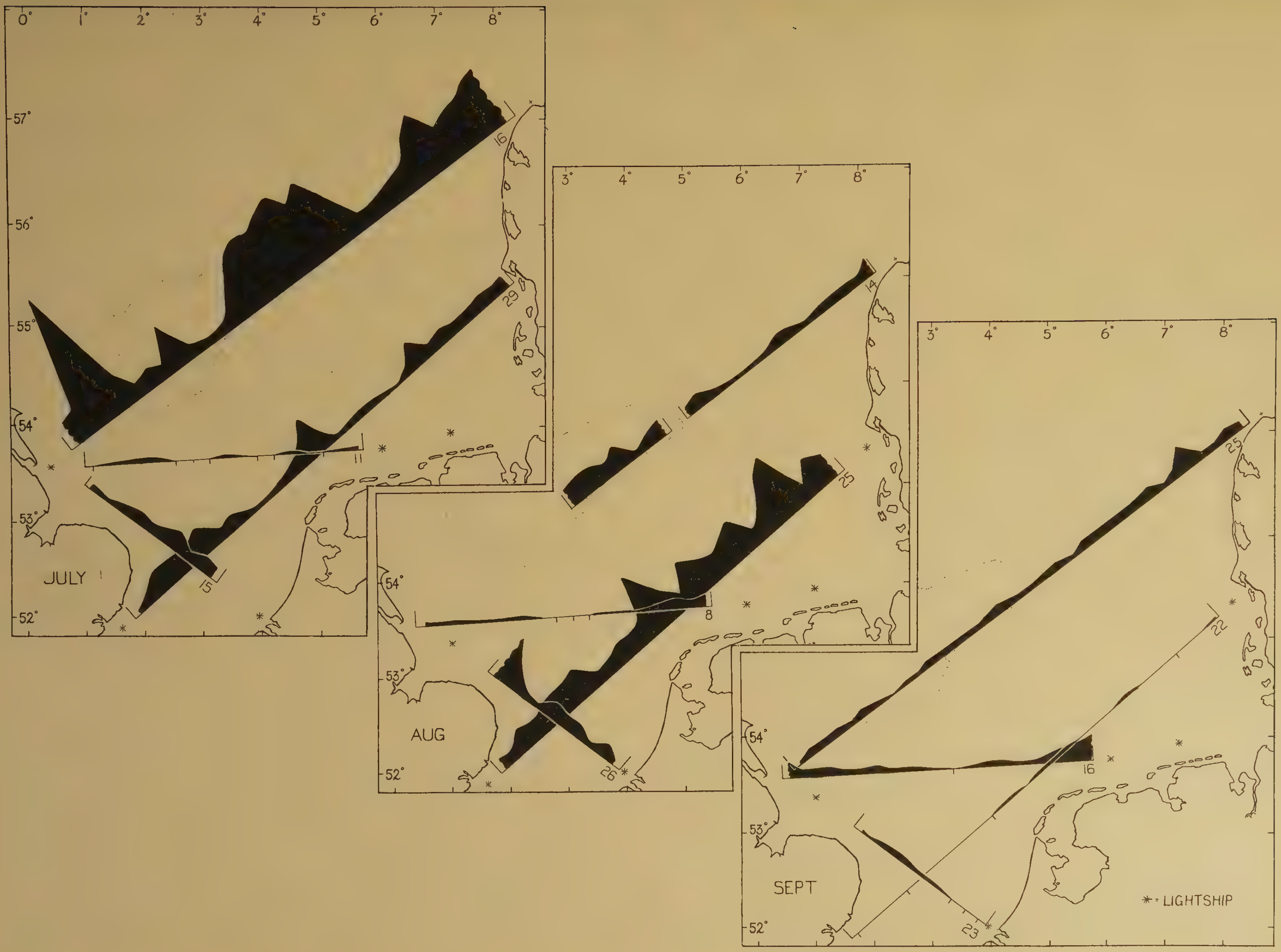

JULY
AUG
SEPT
OCT
NOV
DEC
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
AUG 1
26
23
29
B.30
27
27 B.
24
13
25
29
7
25
26
19
16
6
✱ = LIGHTSHIP

TOTAL COPEPODA, *July - December, 1936. For further explanation see Plate XCIV.*

PLATE CIV

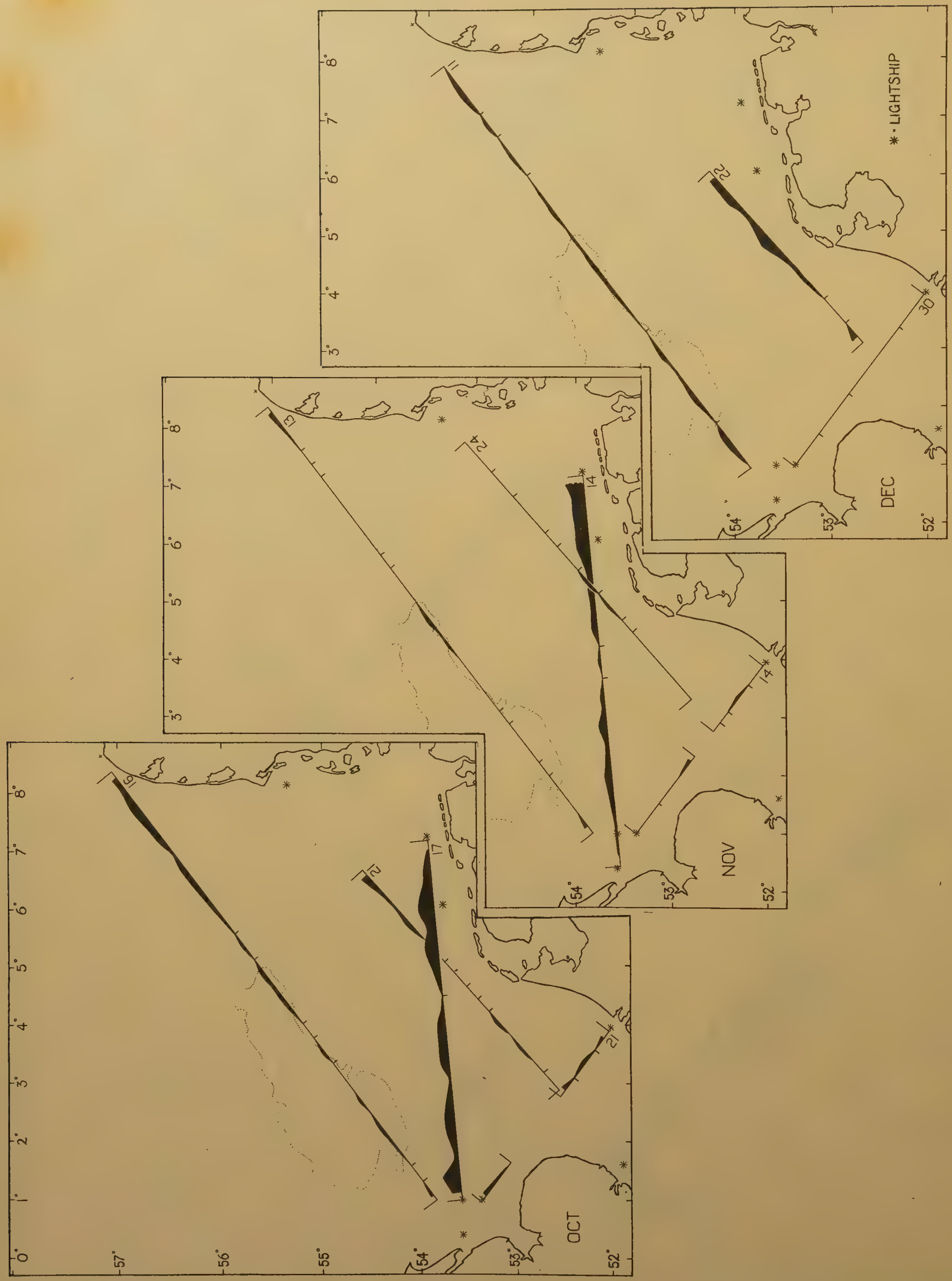

JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
24
2
13
17
21
25
9
10
14
22
8
11
16
20
19
17
✱ = LIGHTSHIP

TOTAL COPEPODA, *January – June, 1937.* *For further explanation see Plate XCIV.*


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
29
11
15
JULY
14
25
8
26
AUG
22
16
23
SEPT
✱ = LIGHTSHIP

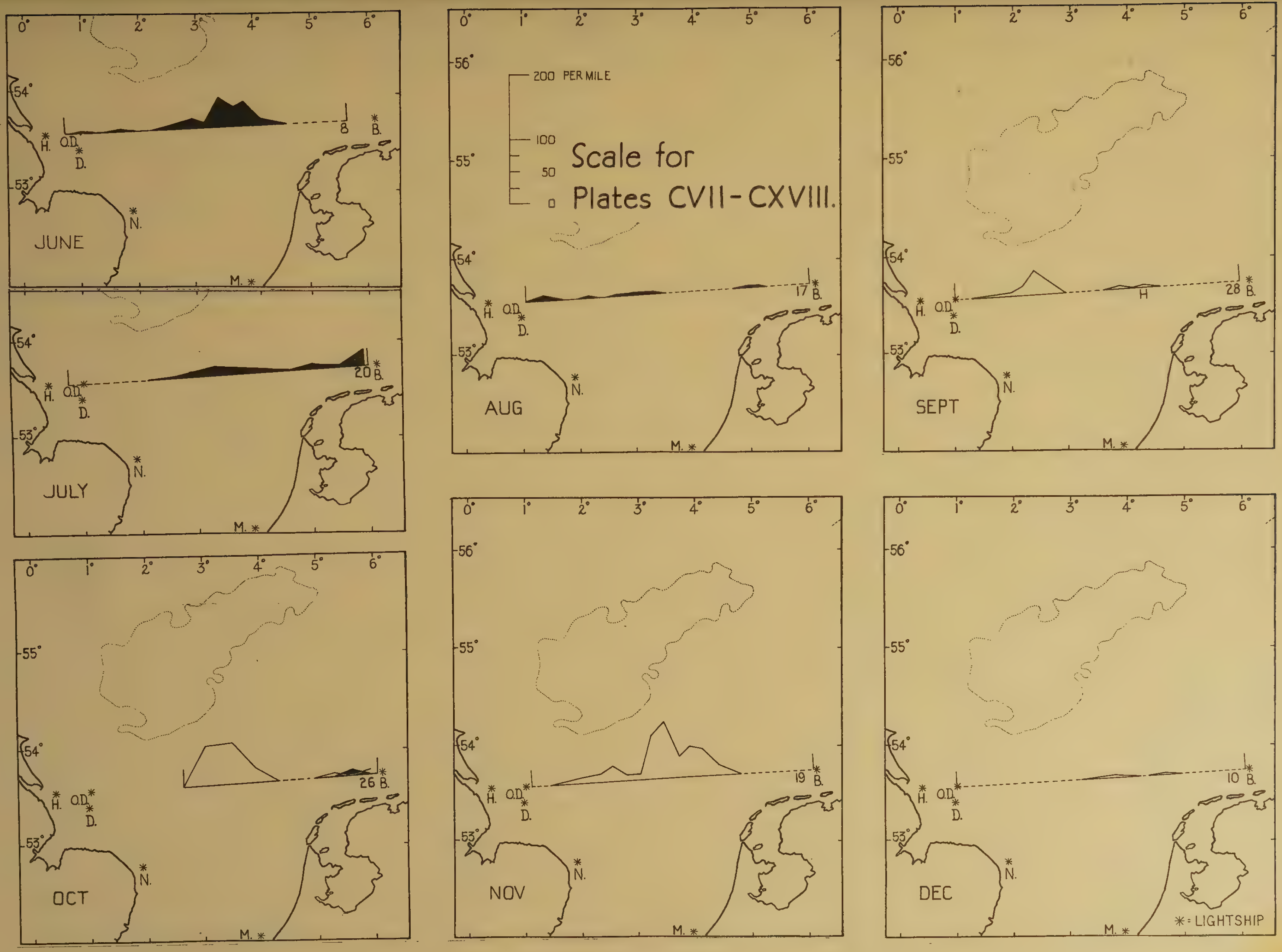
TOTAL COPEPODA, *July – September, 1937.* *For further explanation see Plate XCIV.*

PLATE CVI



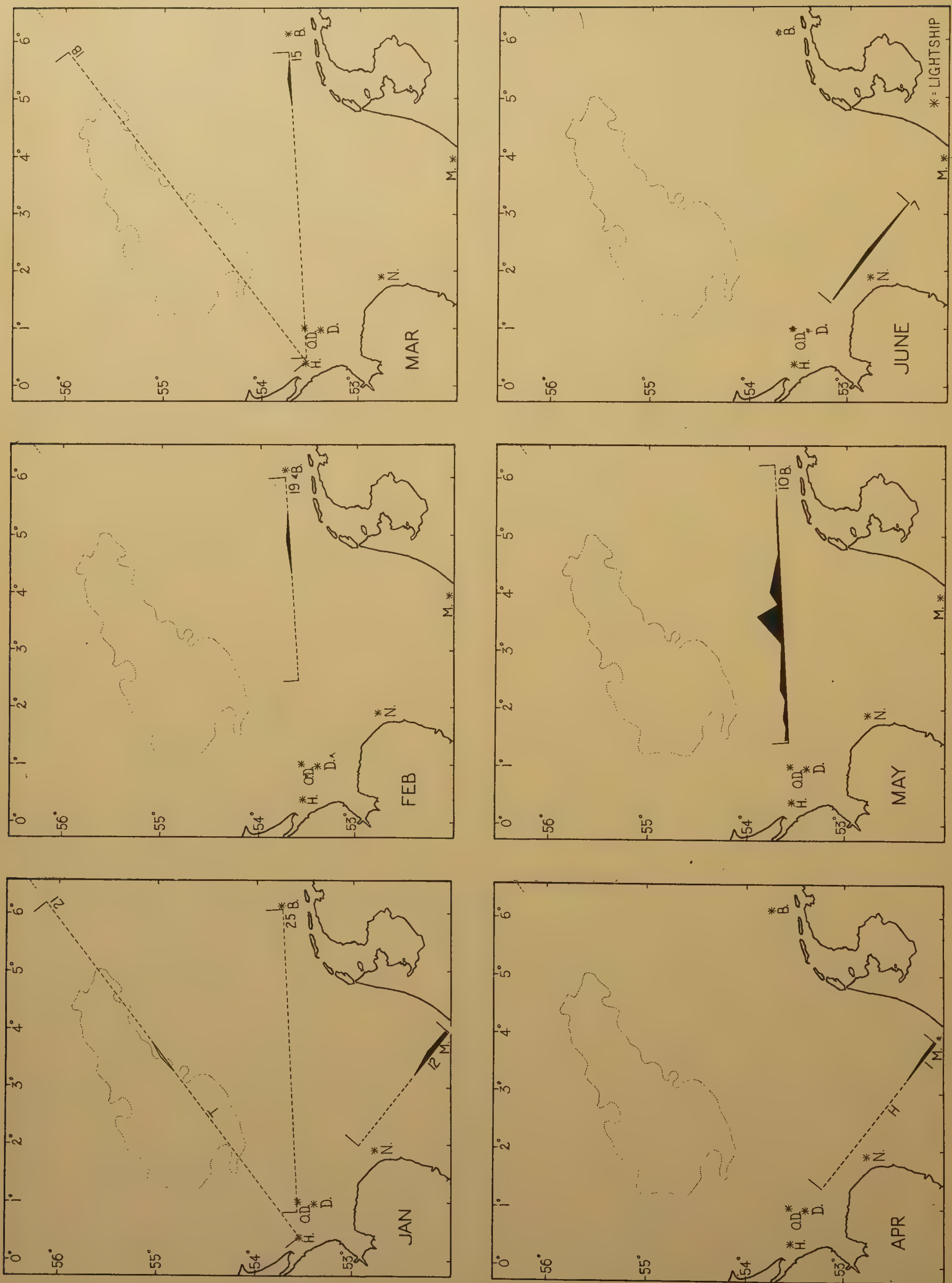
* - LIGHTSHIP
OCT
NOV
DEC
0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
19
12
17
21
13
24
14
14
11
12
30

TOTAL COPEPODA. *October – December, 1937. For further explanation see Plate XCIV.*

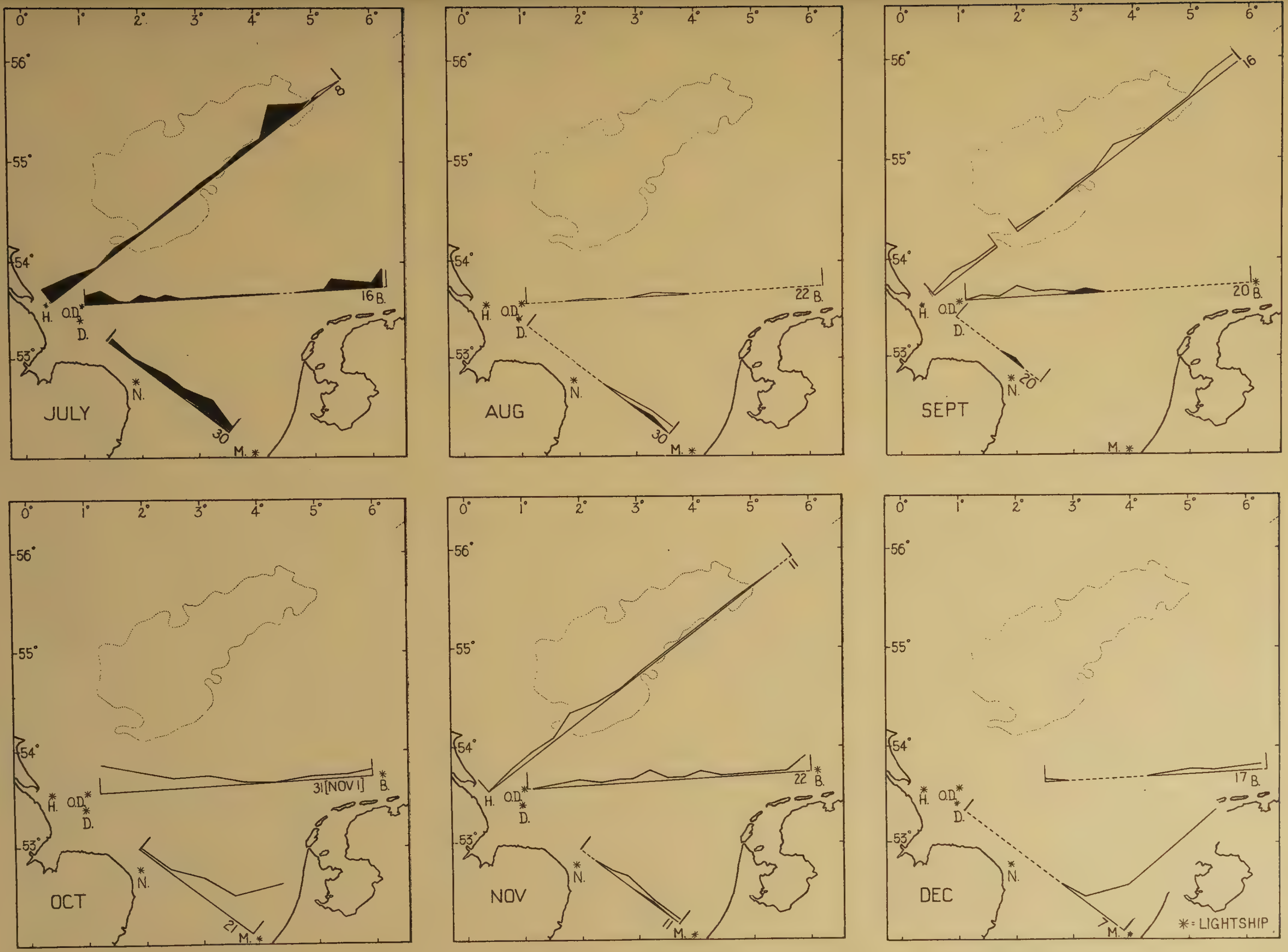

JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
200 PER MILE
100
50
0
Scale for Plates CVII-CXVIII.
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
8
20
17
28
26
19
10
H
✱ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked in graphs and 'H' for traces) and* ***C. TYPICUS*** *(open line) June – December, 1932. General arrangements as explained on Plate XCIV.*

PLATE CVIII

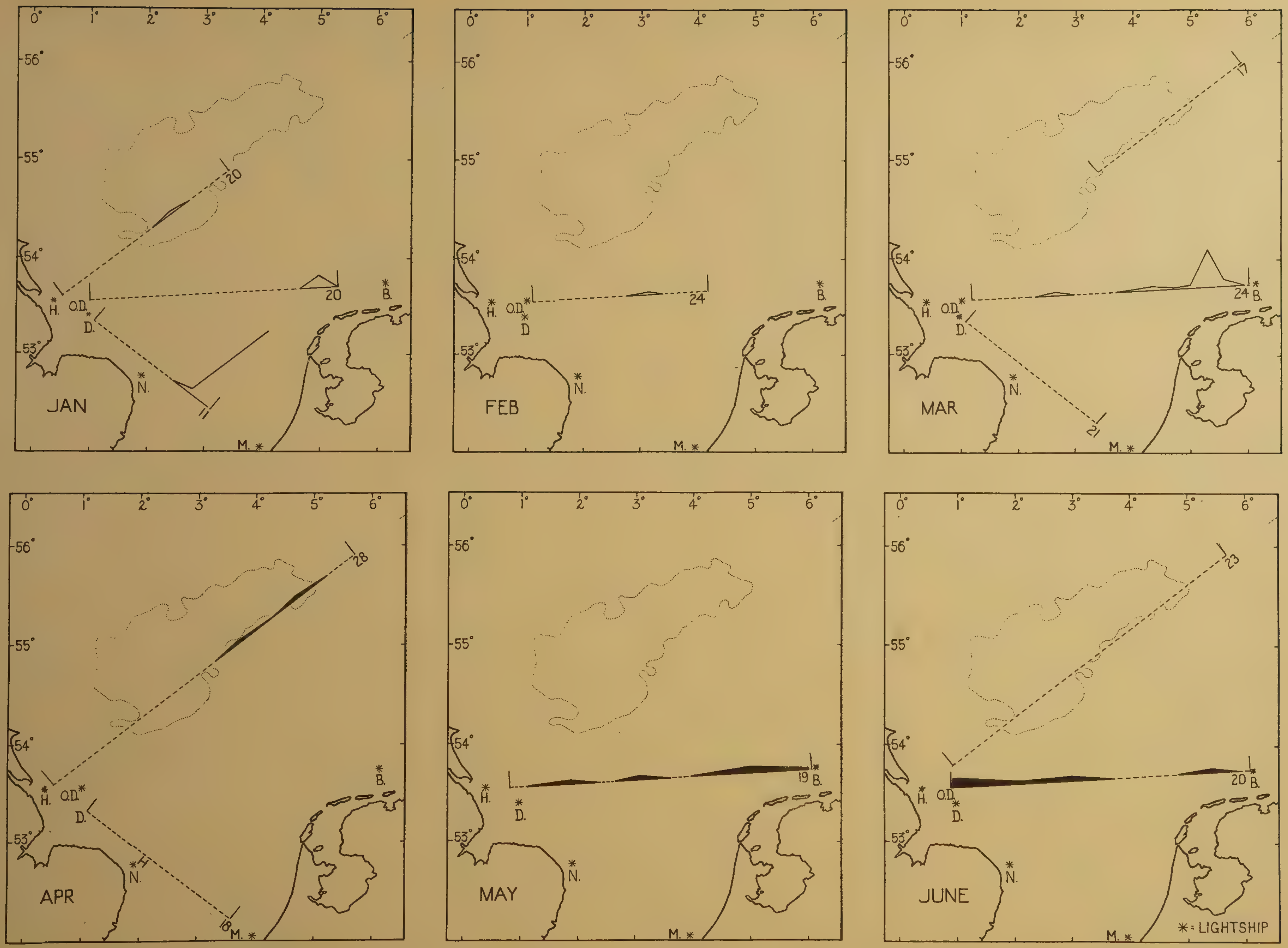

JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
H.
O.D.
D.
N.
M.
B.
25
12
19
15
10
18
12
✱ = LIGHTSHIP

CENTROPAGES HAMATUS (blacked-in in graphs and 'H' for traces) and **C. TYPICUS**
(open line and 'T' for traces) January–June, 1933. *General arrangements as explained on Plate XCIV.*

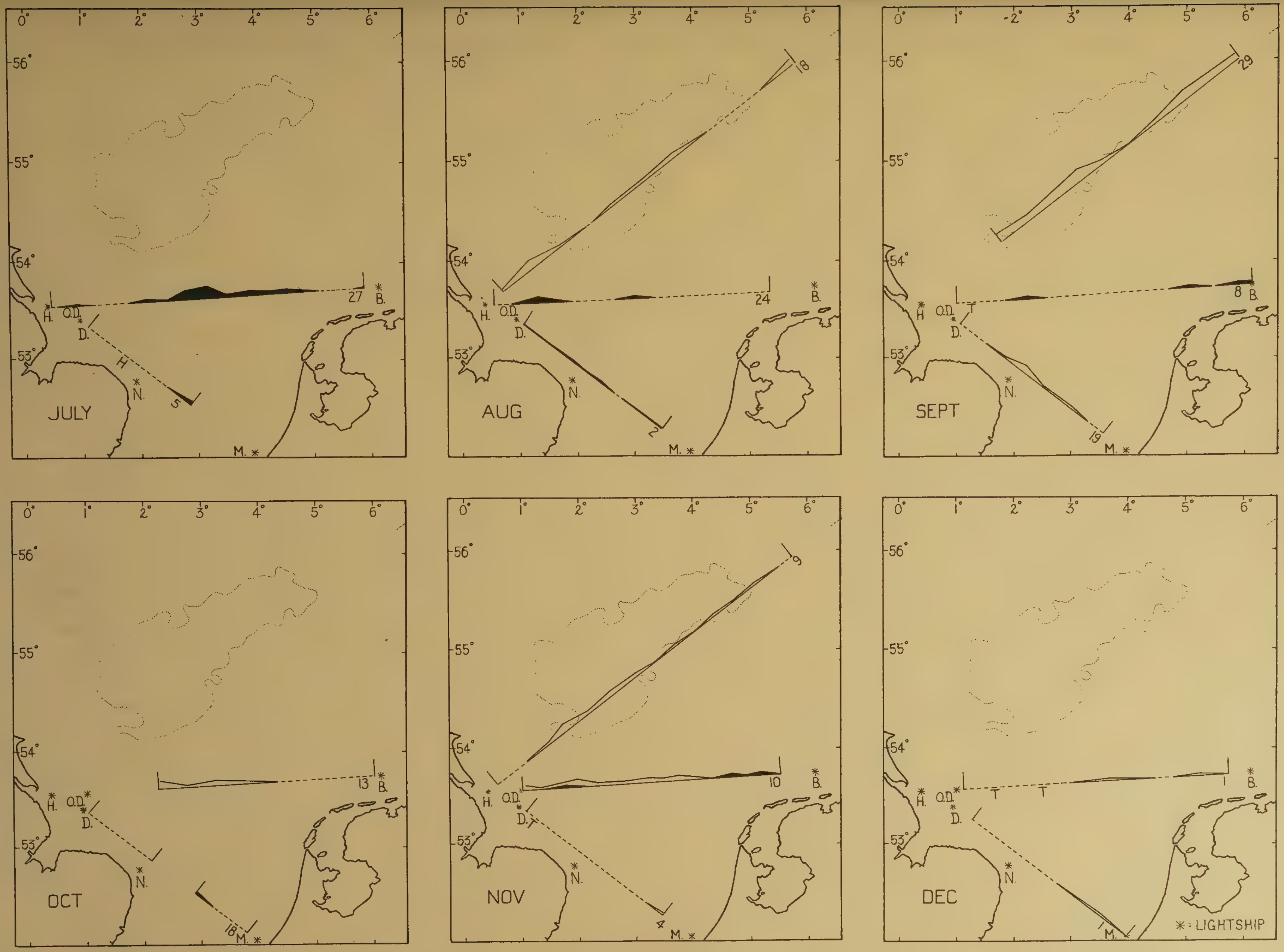

0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
JULY
AUG
SEPT
OCT
NOV
DEC
H.
O.D.
D.
N.
M.
B.
8
16 B.
30
22 B.
16
20 B.
20
21
31 [NOV 1]
22
11
17 B.
* = LIGHTSHIP

CENTROPAGES HAMATUS (blacked-in graphs) and **C. TYPICUS** (open line) July – December, 1933. General arrangement as explained on Plate XCIV.

PLATE CX

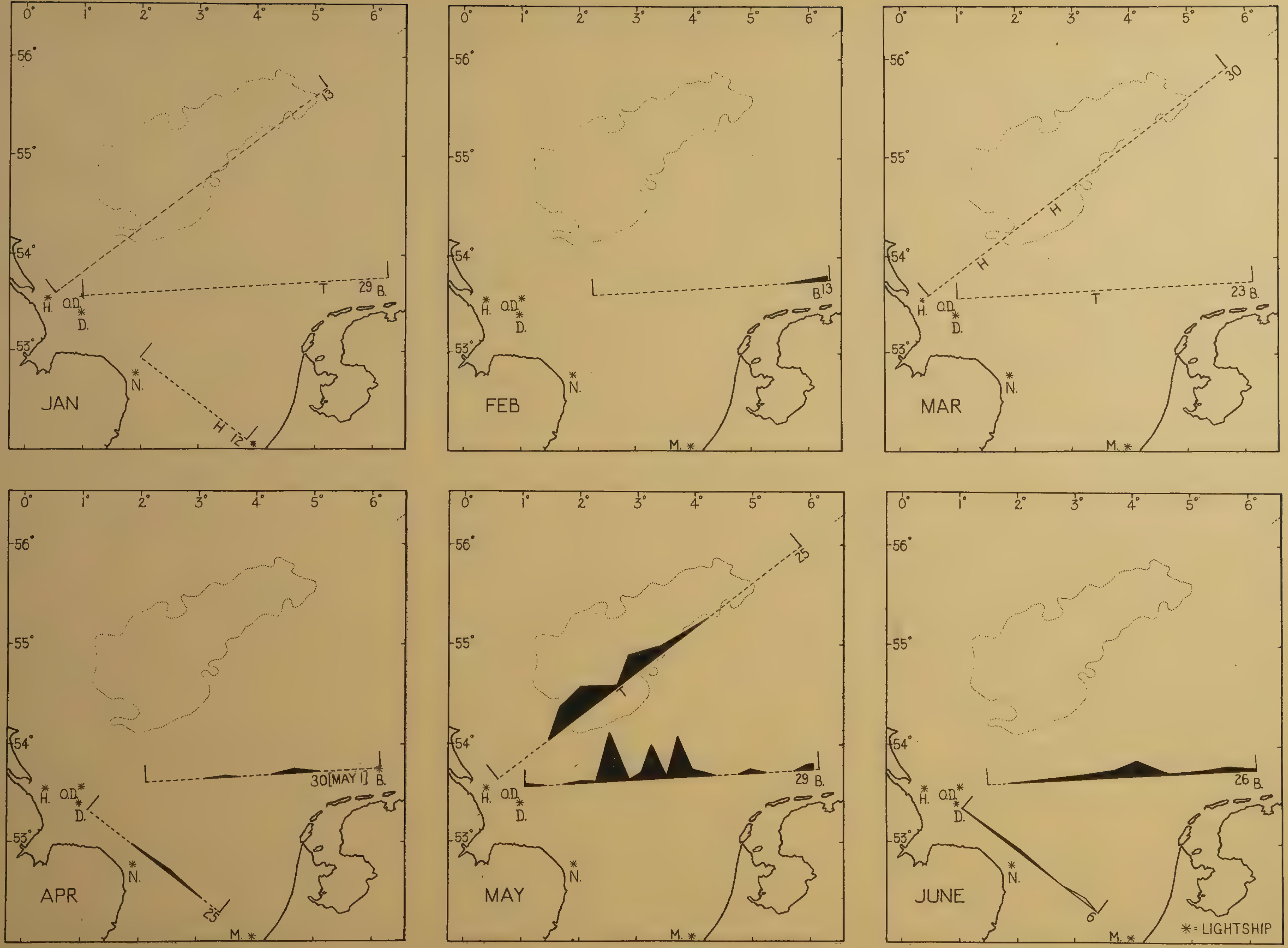

JAN
FEB
MAR
APR
MAY
JUNE
0° 1° 2° 3° 4° 5° 6°
56° 55° 54° 53°
H.
O.D.
D.
N.
M.
B.
20
20
11
24
17
24
21
28
18
H
19
23
20
✳ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and*
C. TYPICUS *(open line) January—June, 1934. General arrangements as explained on Plate XCIV.*

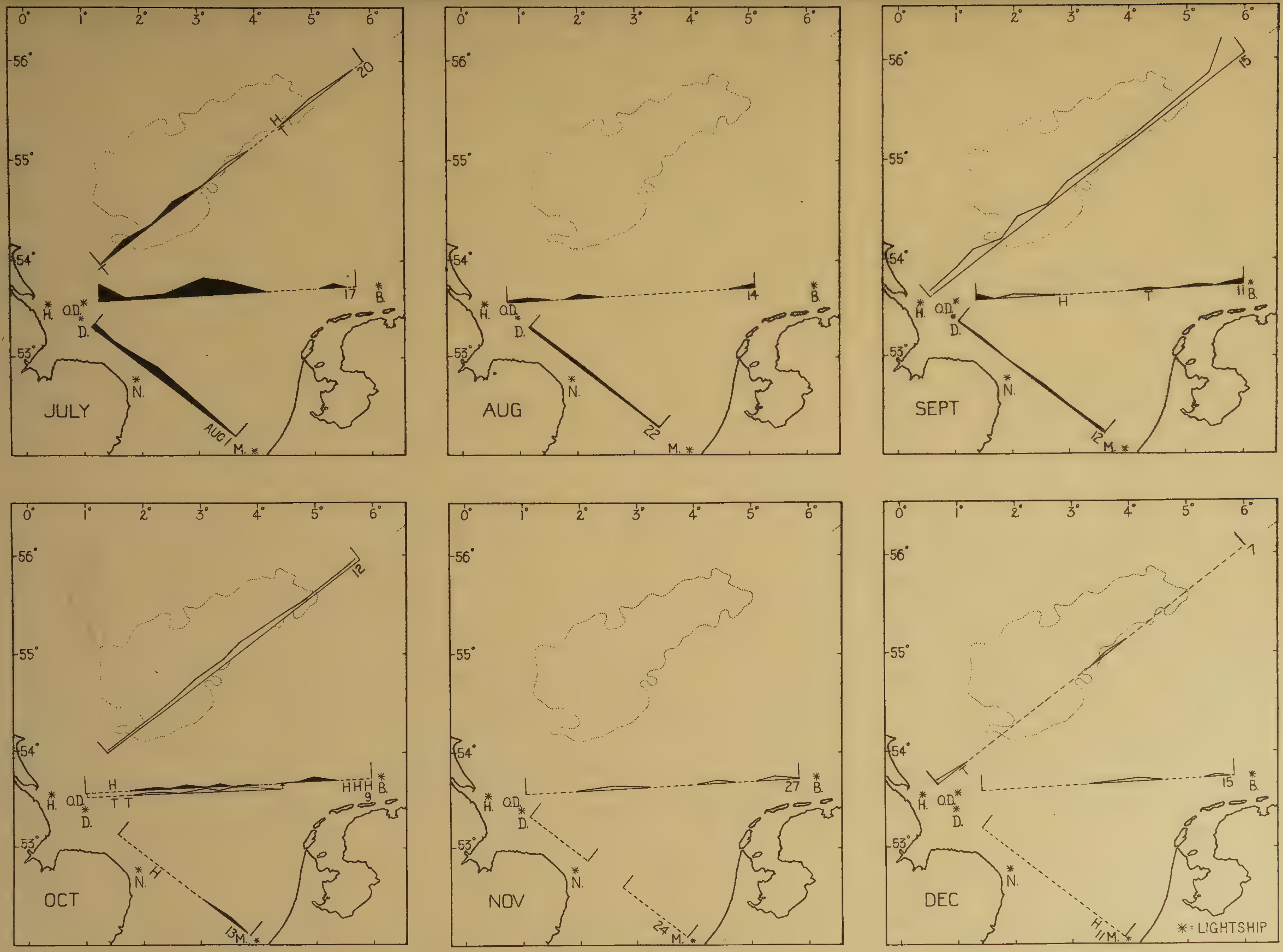

JULY
AUG
SEPT
OCT
NOV
DEC
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
T
27
5
24
18
2
29
8
19
13
18
10
9
4
1
✳ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* **C. TYPICUS** *(open line and 'T' for traces) July–December, 1934. General arrangement as explained on Plate XCIV.*

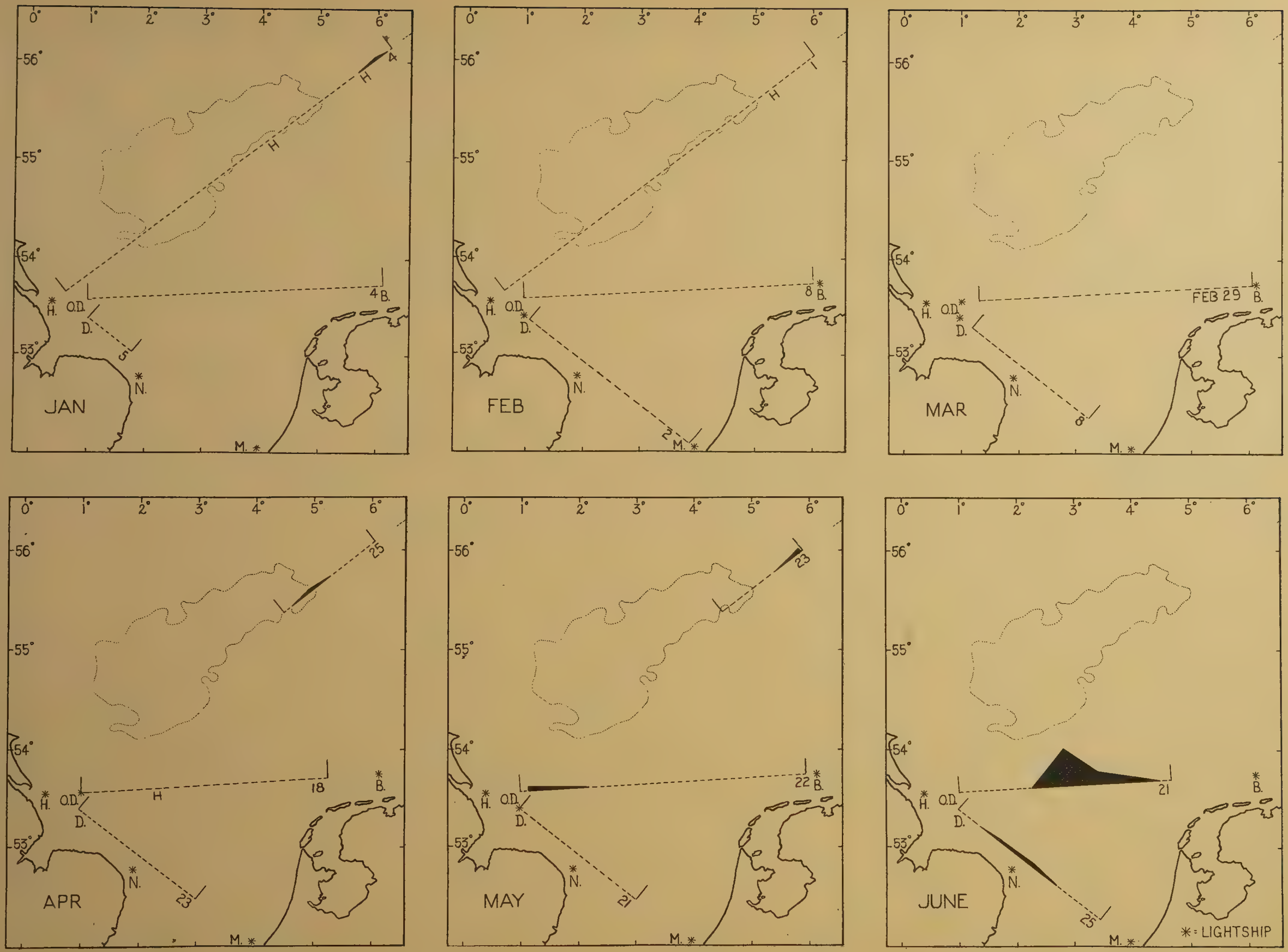
PLATE CXII


JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
T
H
29
13
30
23
12
25
30 [MAY 1]
26
6
*= LIGHTSHIP

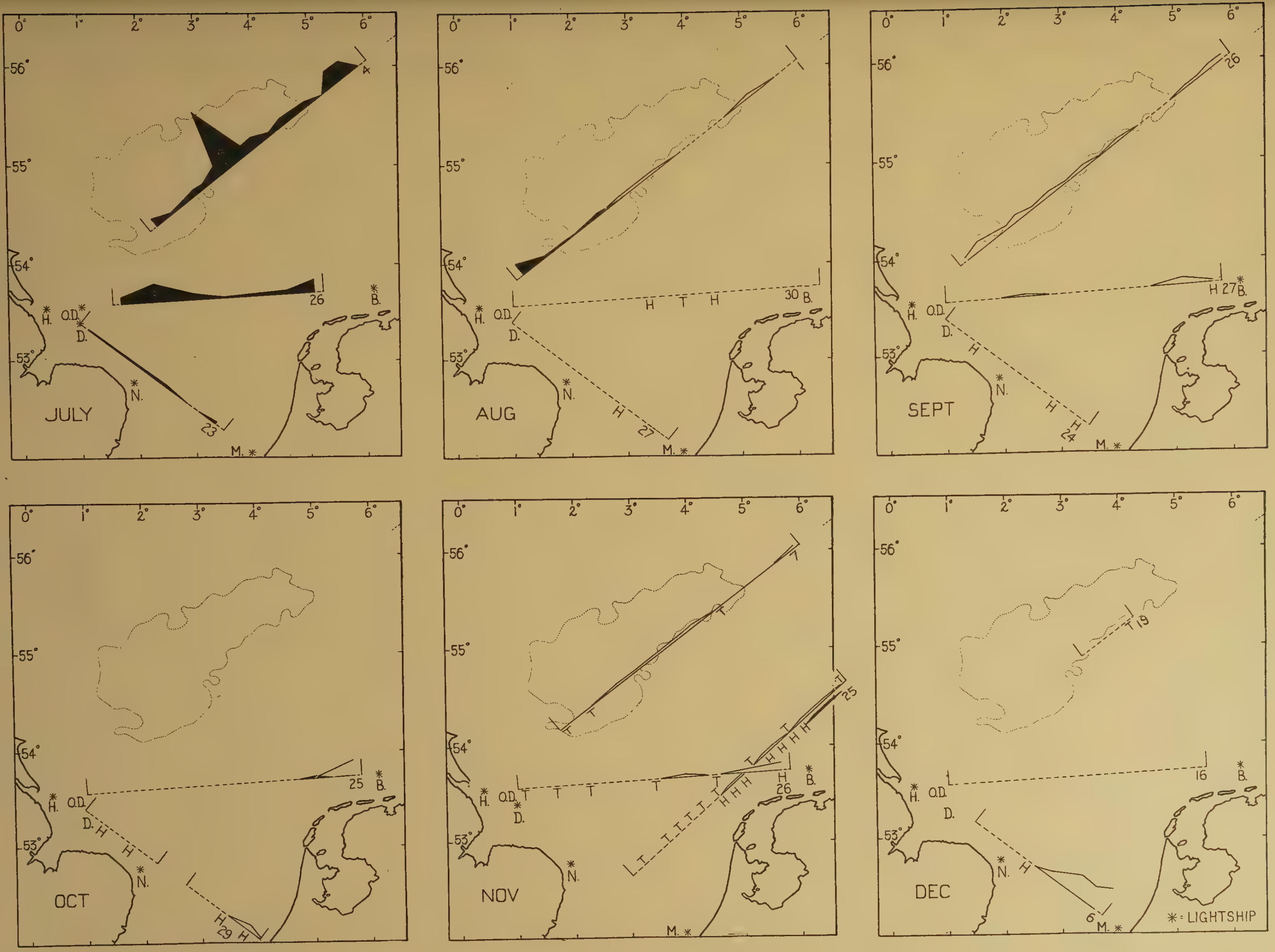
CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* **C. TYPICUS** *(open line and 'T' for traces) January – June, 1935. General arrangement as explained on Plate XCIV.*


JULY
AUG
SEPT
OCT
NOV
DEC
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
AUG 1
20
17
22
14
12
15
11
13
9
24
27
1
H
T
HHH
✳ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* **C. TYPICUS** *(open line, and 'T' for traces) July-December, 1935. General arrangement as explained on Plate XCIV.*

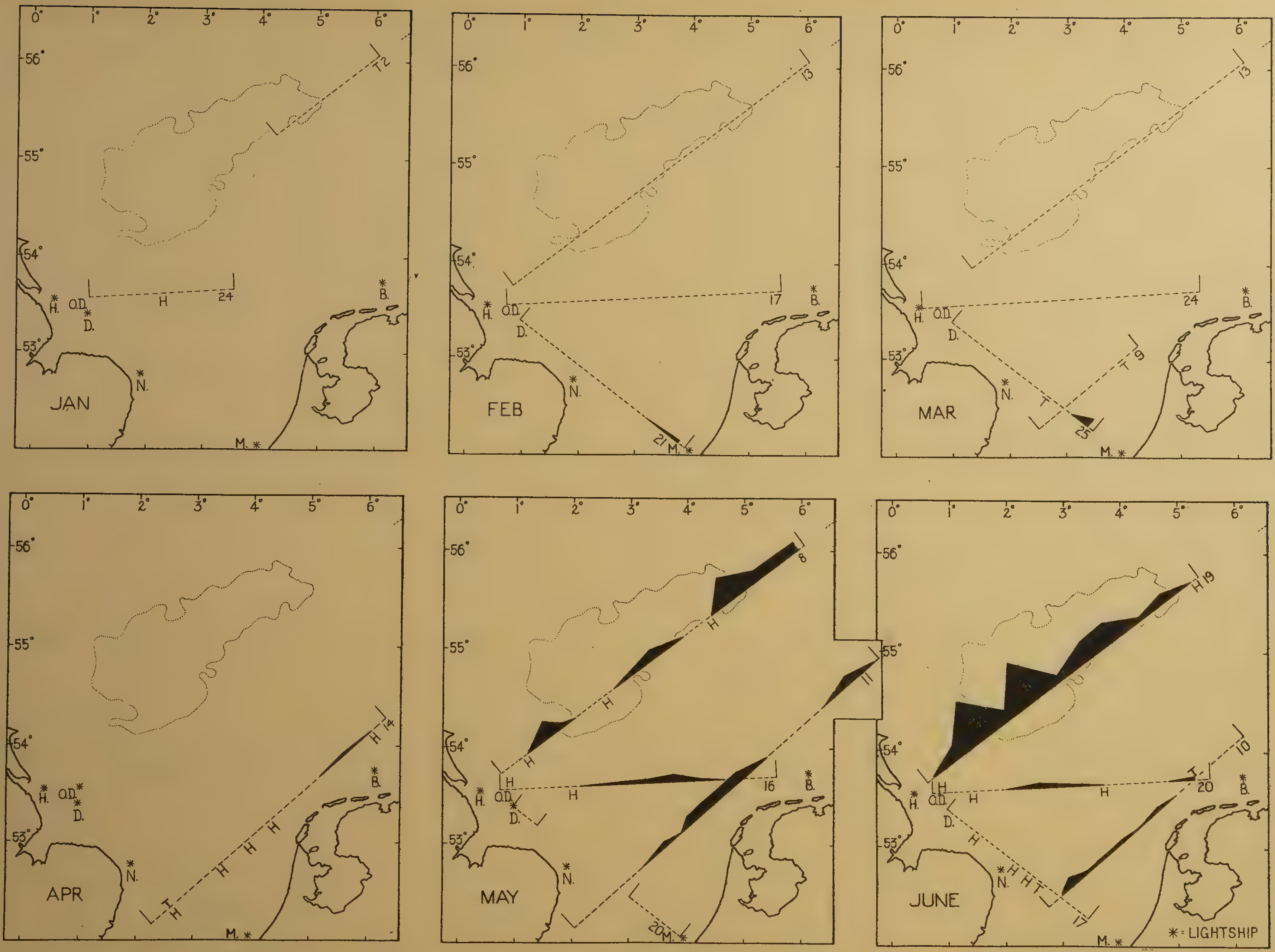

JAN
FEB
MAR
APR
MAY
JUNE
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
H
4
5
8
2
FEB 29
18
23
25
22
21
✱ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and*
C. TYPICUS *(open line) January - June, 1936. General arrangement as explained on Plate XCIV.*

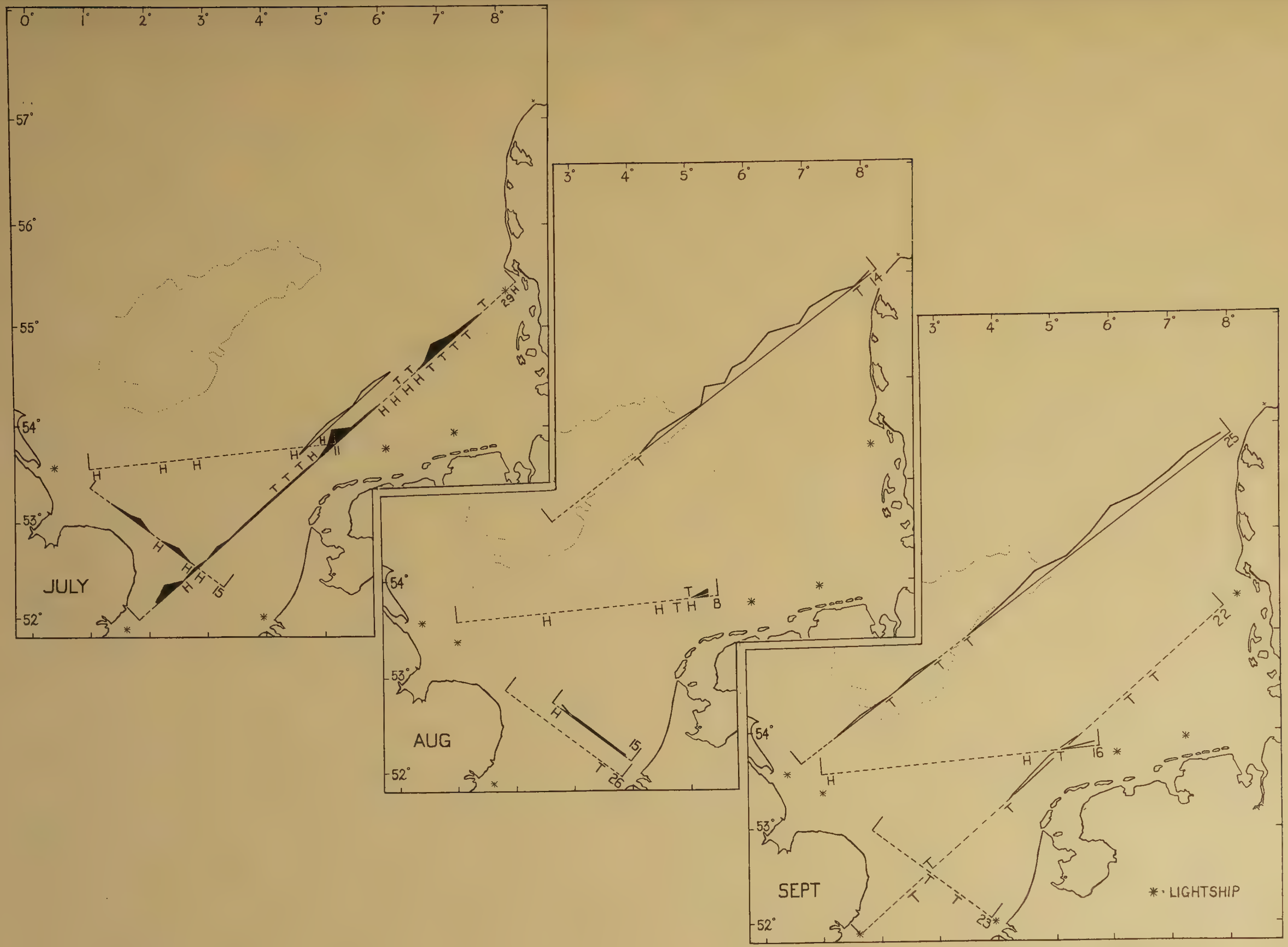

JULY
AUG
SEPT
OCT
NOV
DEC
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
23
26
4
30
27
H
T
24
H 27
25
29
19
16
6
✱ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* **C. TYPICUS** *(open line and 'T' for traces) July–December, 1936. General arrangement as explained on Plate XCIV.*

PLATE CXVI

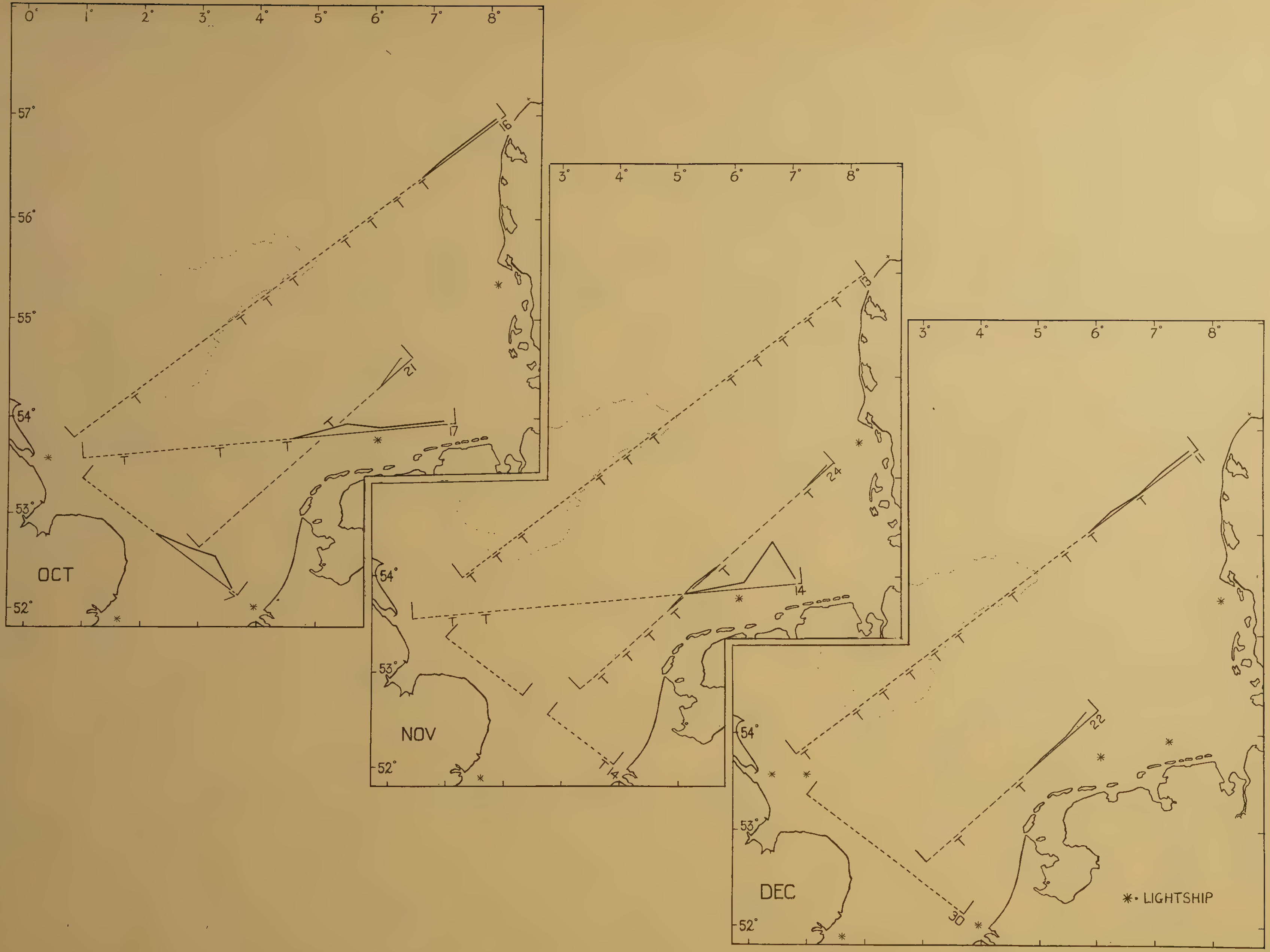

JAN
FEB
MAR
APR
MAY
JUNE
H. O.D. D. N. M. B.
✱ = LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* ***C. TYPICUS*** *(open line and 'T' for traces) January–June, 1937. General arrangement as explained on Plate XCIV.*


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
JULY
AUG
SEPT
29
15
11
14
26
22
25
16
23
H
T
B
✱ · LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs and 'H' for traces) and* **C. TYPICUS** *(open line and 'T' for traces) July–September, 1937. General arrangement as explained on Plate XCIV.*

PLATE CXVIII


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
21
17
OCT
13
24
14
NOV
11
22
30
DEC
T
✱ • LIGHTSHIP

CENTROPAGES HAMATUS *(blacked-in graphs) and* **C. TYPICUS** *(open line and 'T' for traces) October-December, 1937. General arrangement as explained on Plate XCIV.*

Explanation of

PLATES CXIX-CXXV

showing the distribution of

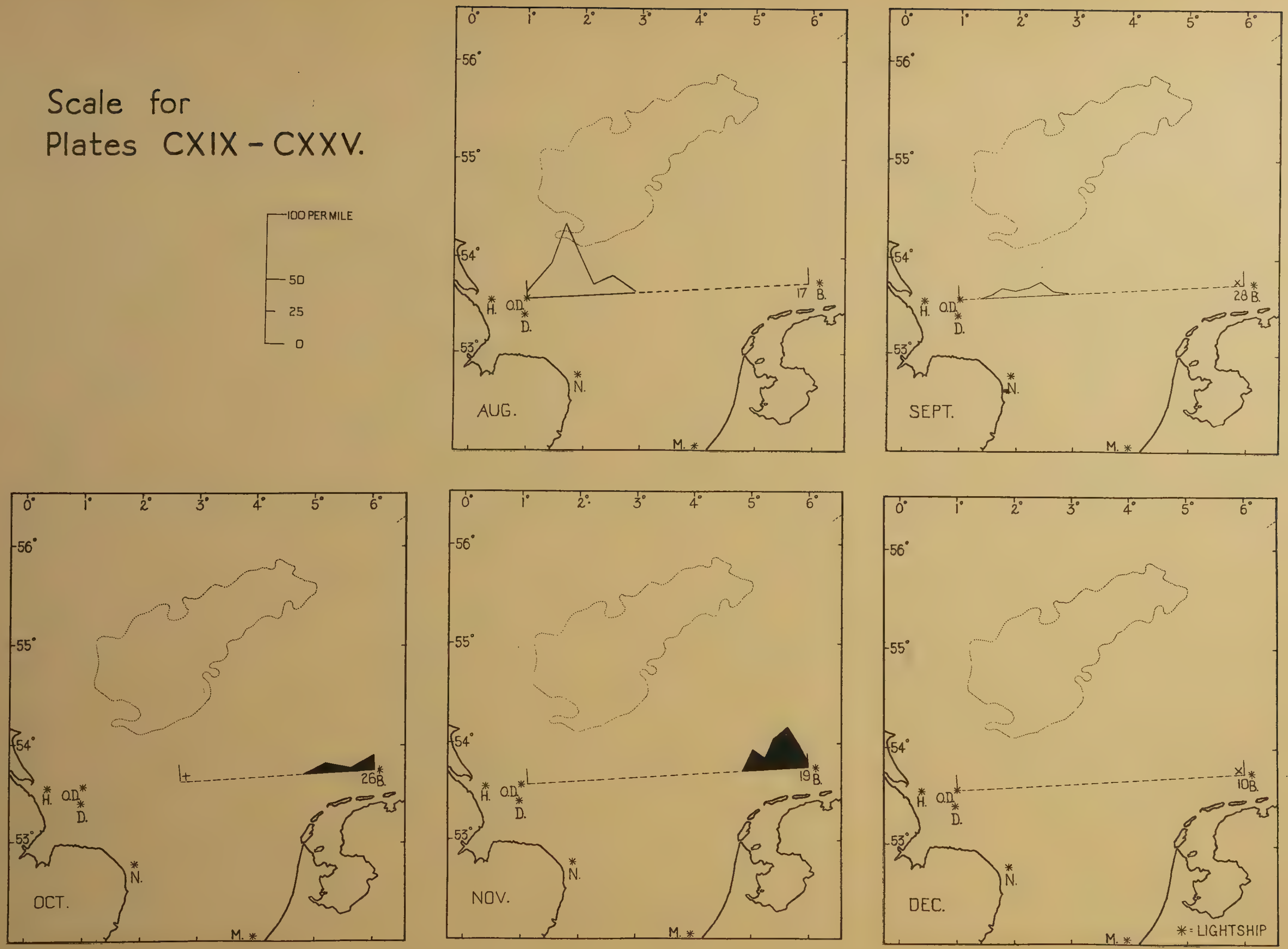
ISIAS CLAVIPES and ***CORYCAEUS ANGLICUS***

June 1932 — December 1937.

These species were usually only found in the latter part of the year. Charts for the earlier months have been omitted, but the records analysed, being the same as those for *CENTROPAGES*, are shown as on previous plates.

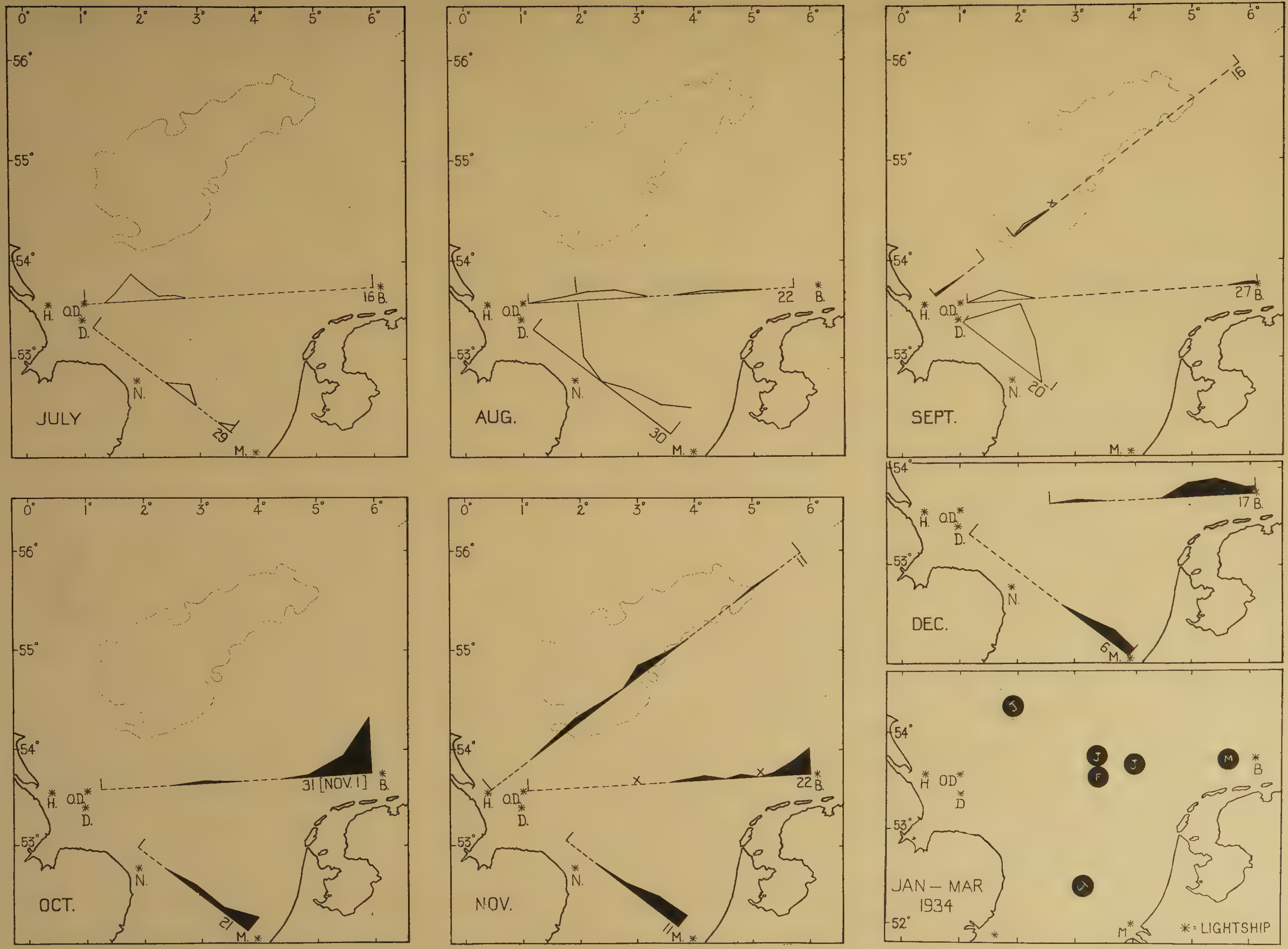
Occasionally *CORYCAEUS ANGLICUS* was recorded in January, February or March. Such traces are represented by black circles containing the initial letters of the months. They are placed in their correct position on the previous December chart, except on Plate CXX when an extra chart is inserted.

Scale for
Plates CXIX - CXXV.


100 PER MILE
50
25
0
AUG.
SEPT.
OCT.
NOV.
DEC.
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
17 B.
28 B.
26 B.
19 B.
10 B.
✱ = LIGHTSHIP

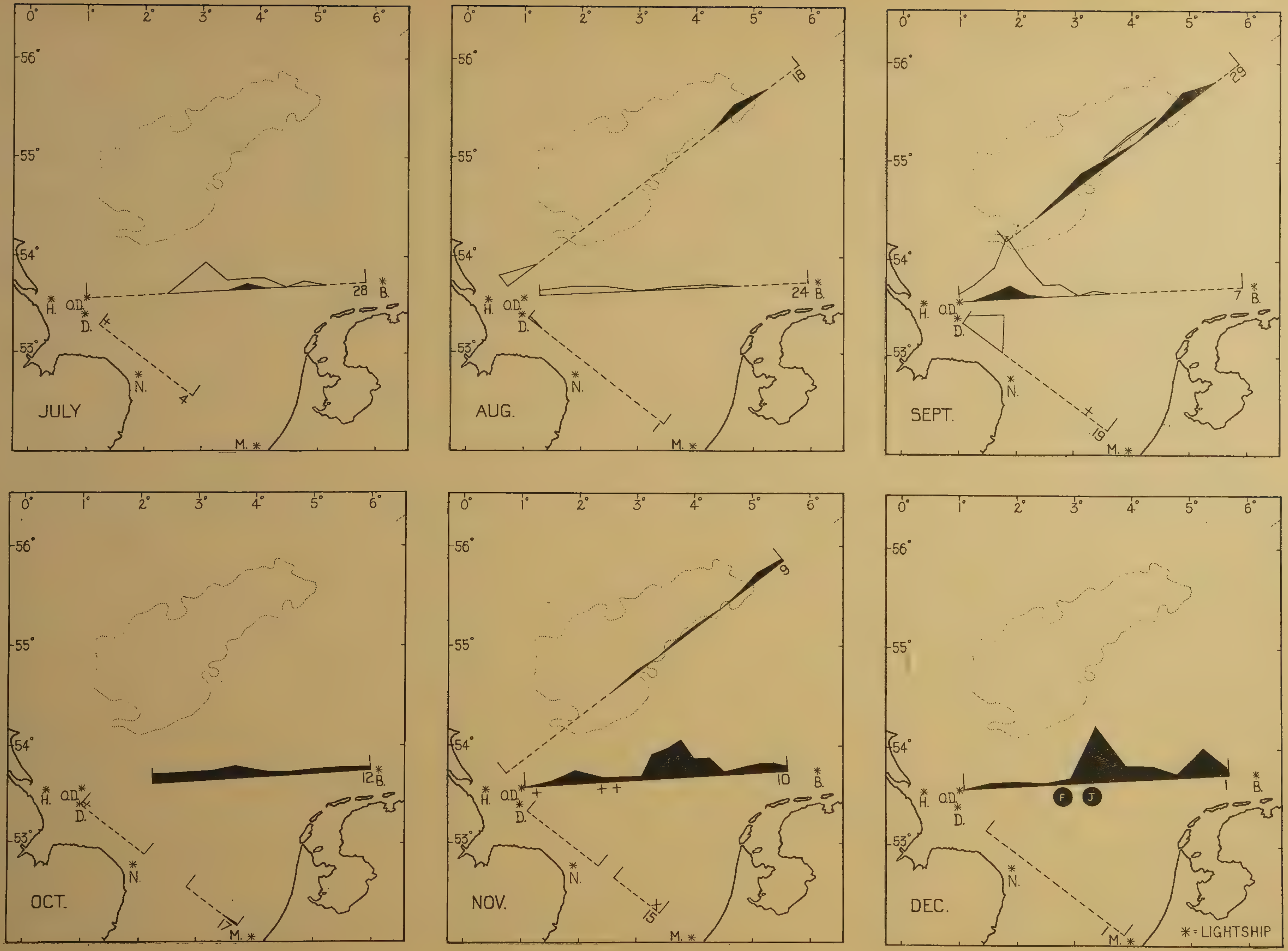
ISIAS CLAVIPES *(open line and + for traces) and* ***CORYCAEUS ANGLICUS*** *(blacked-in graph and × for traces) 1932.* *For further explanation see previous page.*

PLATE CXX


0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
52°
H.
O.D.
D.
N.
M.
B.
JULY
16
29
AUG.
22
30
SEPT.
27
20
16
DEC.
17
6
OCT.
31 [NOV. 1]
21
NOV.
22
11
JAN – MAR
1934
J
J
F
J
M
J
✳ = LIGHTSHIP

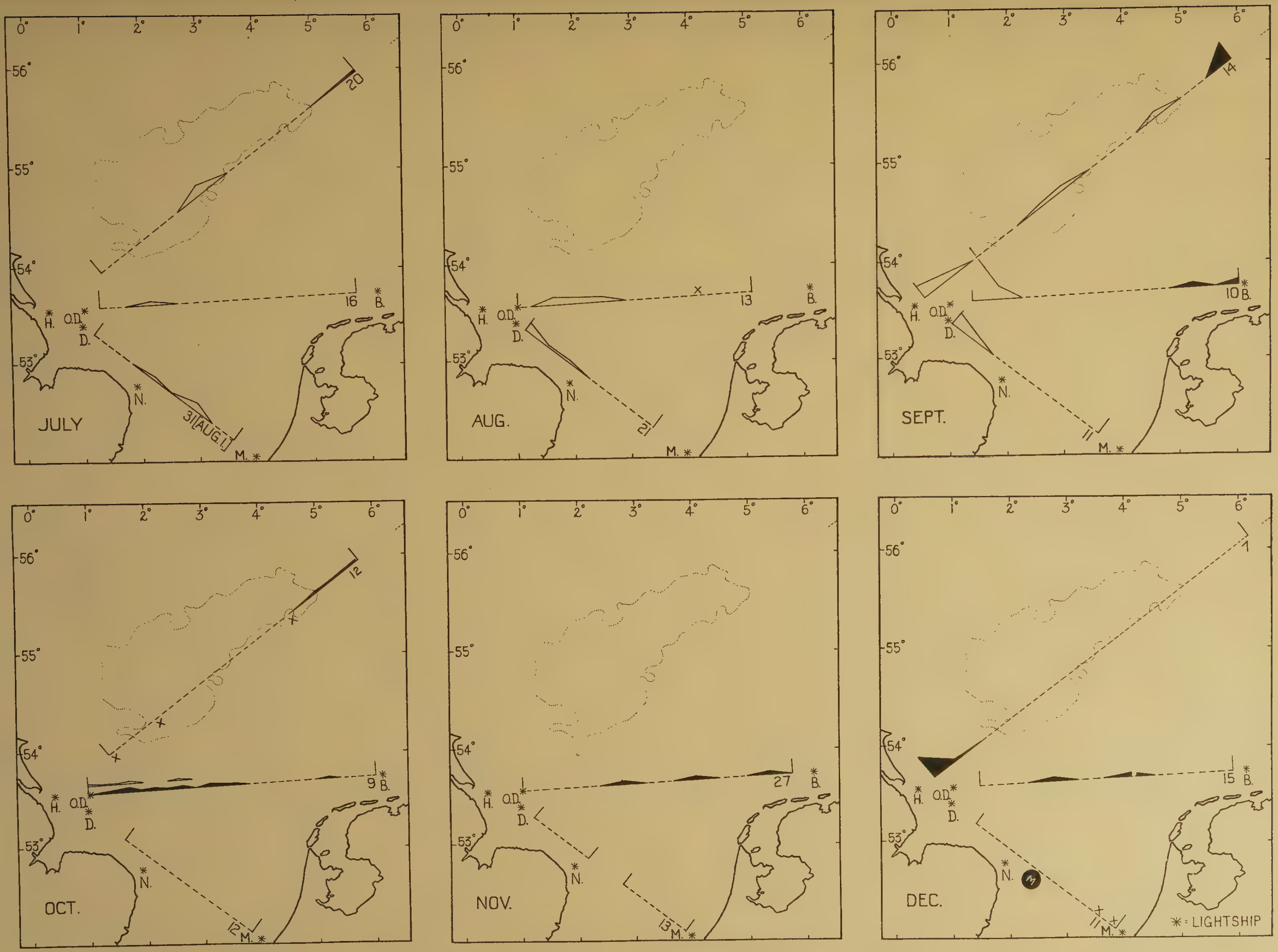
ISIAS CLAVIPES (open line) and **CORYCAEUS ANGLICUS** (blacked-in graph and x for traces) 1933. For further explanation see page preceding Plate CX/X.

PLATE CXXI


JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
H.
O.D.
D.
N.
M.
B.
28
4
24
18
29
7
19
12
17
9
10
15
1
F
J
0° 1° 2° 3° 4° 5° 6°
53° 54° 55° 56°
✱ = LIGHTSHIP

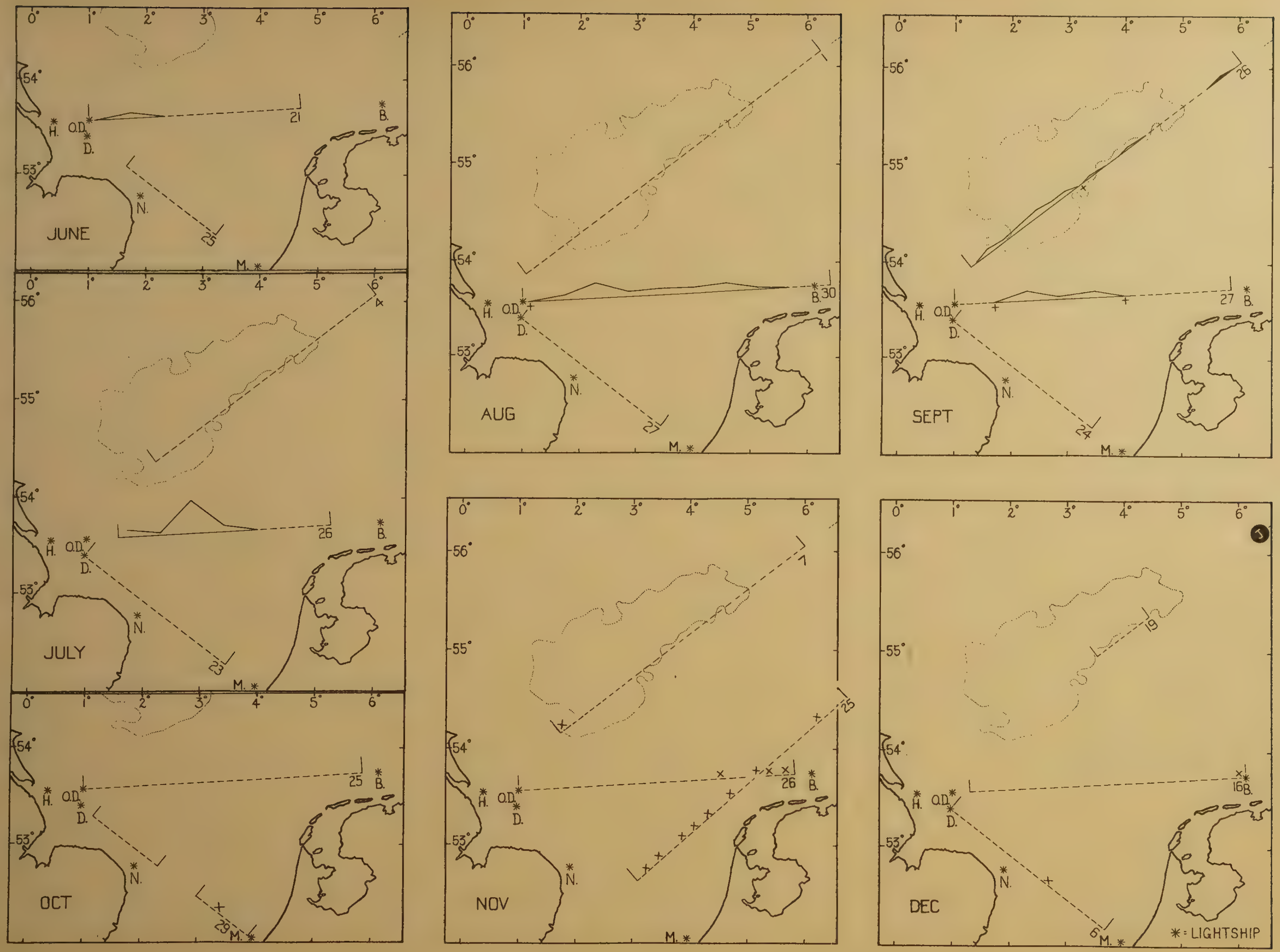
ISIAS CLAVIPES (open line and + for traces) and *CORYCAEUS ANGLICUS* (blacked-in graph and × for traces) 1934. For further explanation see page preceding Plate CXIX.

PLATE CXXII


JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
0°
1°
2°
3°
4°
5°
6°
56°
55°
54°
53°
H.
O.D.
D.
N.
M.
B.
20
16
31 [AUG. 1]
13
21
14
10
11
12
9
27
15
1
✳ = LIGHTSHIP

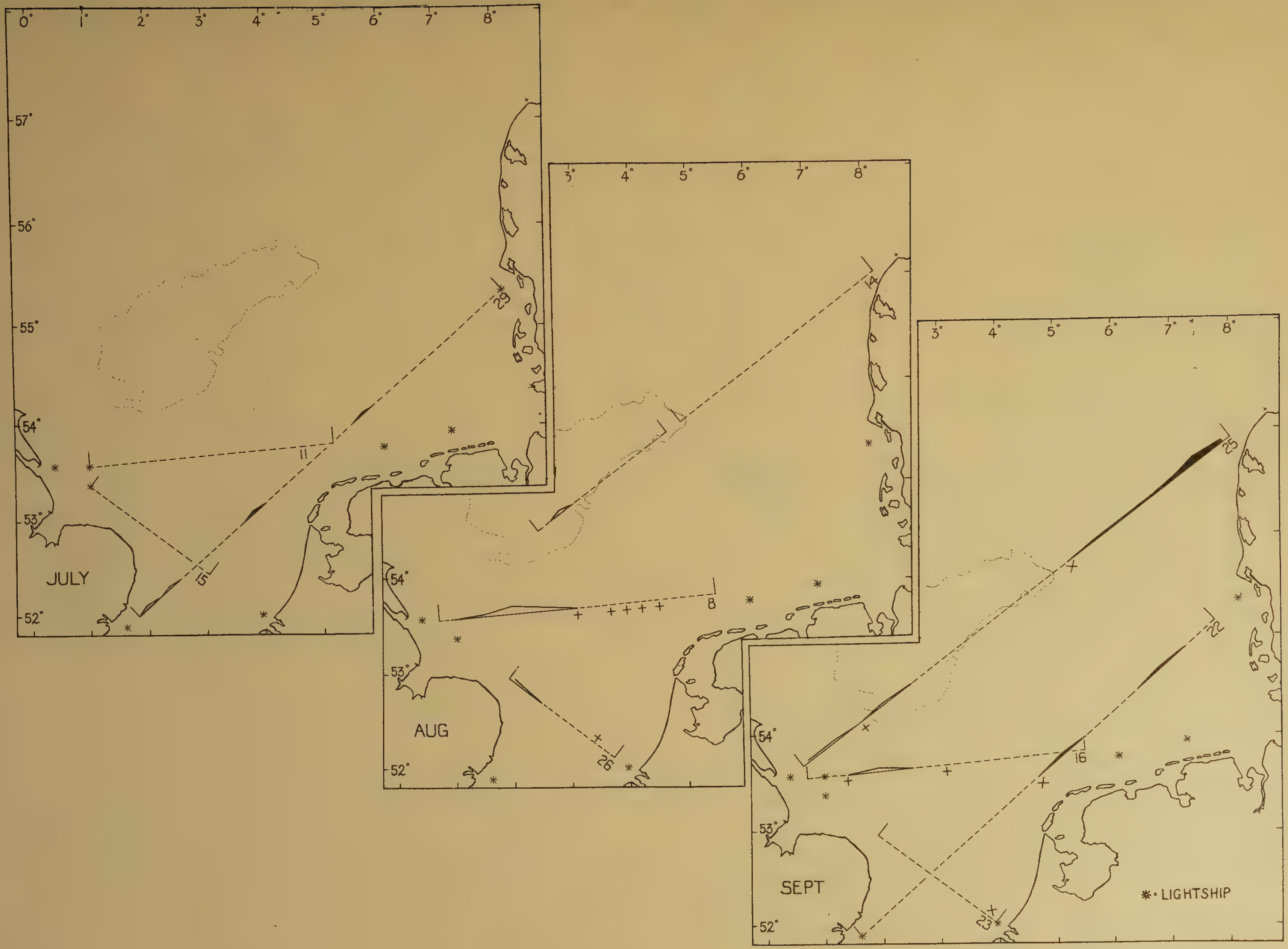
ISIAS CLAVIPES *(open line) and* ***CORYCAEUS ANGLICUS*** *(blacked-in graph and × for traces) 1935.* *For further explanation see page preceding Plate CXIX.*

PLATE CXXIII


JUNE
JULY
OCT
AUG
NOV
SEPT
DEC
H.
O.D.
D.
N.
M.
B.
0°
1°
2°
3°
4°
5°
6°
53°
54°
55°
56°
21
25
26
23
29
30
27
24
16
19
✱ = LIGHTSHIP

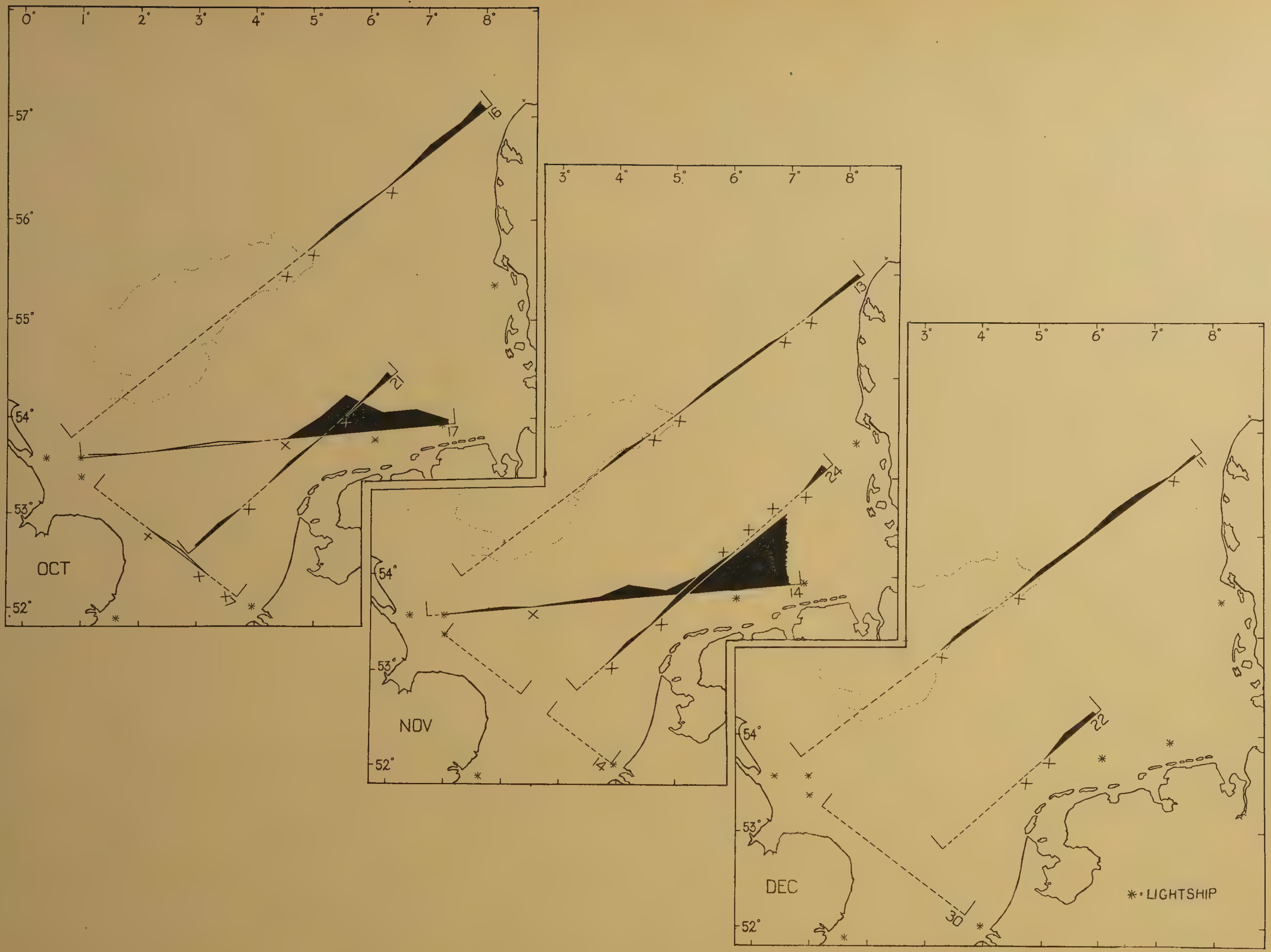
ISIAS CLAVIPES *(open line and + for traces) and* ***CORYCAEUS ANGLICUS*** *(blacked-in graph and x for traces) 1936. For further explanation see page preceding Plate CXIX.*

PLATE CXXIV


0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
JULY
29
11
15
AUG
14
8
26
SEPT
25
22
16
23
✱ - LIGHTSHIP

ISIAS CLAVIPES *(open line and + for traces) and* ***CORYCAEUS ANGLICUS*** *(blacked-in graph and X for traces) 1937, part I. For further explanation see page preceding Plate CXIX.*

PLATE CXXV



0°
1°
2°
3°
4°
5°
6°
7°
8°
57°
56°
55°
54°
53°
52°
16
21
17
OCT
13
24
14
14
NOV
11
22
30
DEC
✱ = LIGHTSHIP

ISIAS CLAVIPES *(open line and + for traces) and* ***CORYCAEUS ANGLICUS*** *(blacked-in graph and X for traces) 1937, part II. For further explanation see page preceding Plate CXIX.*

[*Hull Bulletins of Marine Ecology, Vol. I, No. 5, pp. 239—254, September, 1941.*]

ECOLOGICAL RELATIONS BETWEEN THE HERRING AND THE PLANKTON OFF THE NORTH-EAST COAST OF ENGLAND

BY

C. CHENG, B.Sc.,
Fisheries Research Student in the University College of Hull.

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Phytoplankton 244
Zooplankton 245
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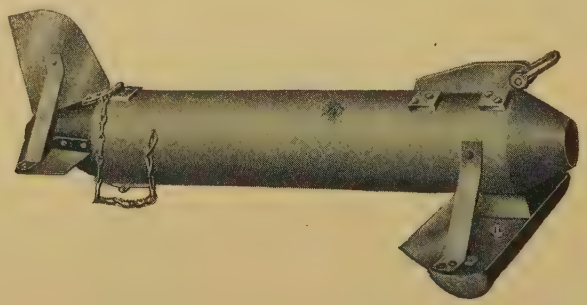
INTRODUCTION.

In the years 1930 to 1934 investigations were carried out from the University College of Hull into the ecological relations between the herring and the plankton by the use of a specially designed instrument, the plankton indicator (Hardy, Henderson, Lucas and Fraser, 1936). The instrument (Text-fig. 1) was issued to the skippers of a number of herring drifters who used it in a standard manner (towing it for a mile on a given length of rope) to collect plankton at the place where they fished for herring. The samples of plankton, which were obtained on a gauze disc, were then wrapped up in calico, provided with a label giving the date, position and number of herring caught, preserved in a tin of formalin and eventually returned to the laboratory for examination. In this way just over 1400 records of herring catches were obtained with accompanying plankton samples for analysis. The statistical treatment of the data so obtained showed firstly that during the summer months when the herring were feeding there was on an average a positive correlation between the number of herring caught and the number of the copepod Calanus in the plankton, and secondly that throughout the year there was a negative correlation between the herring catches and the denser samples of phytoplankton. This led to the commercial application of the instrument as a guide to herring drifters in fishing.[1]

This investigation extended from the region of the Shetland Islands in the north to the East Anglian fishery in the south ; and the most intensive sampling was made in the well-defined area of the Shields herring fishery, where 538 samples were taken during the three summers of 1931, 1932 and 1933 (Text-fig. 2). Due to limitations of time the analysis of the plankton samples for the years 1932 and 1933 was confined to total phytoplankton, the copepod *Calanus finmarchicus*, total Copepoda, the pteropod *Limacina retroversa*, and certain other zooplankton forms.

At Professor Hardy's suggestion, the author undertook a fuller examination of these plankton samples from the Shields area with two objects in view. Firstly to make a brief survey of the main changes in the plankton community in this area during the period of the summer fishery, and secondly, and of more importance, to provide material to enable a comparison to be made between the nature of the plankton and the food taken by the herring during the same period as revealed by the investigations of Mr. Savage of the Ministry of Agriculture and Fisheries (Savage, 1937). Not only had Savage obtained his data from herring stomachs collected by fishermen working in the same fishery, but one of the drifters supplying him with samples in 1932, the S.D. *Violet and Rose*, was a vessel also taking part in the plankton indicator investigations. Savage himself (1926) made a detailed comparison of the Shields plankton with the food of the herring as found by Hardy (1924), and later he made a still more extensive study of the feeding of the herring in relation to the plankton (Savage, 1931). Both authors were much interested in the question as to whether the herring usually feeds by selecting only certain organisms from the plankton, or by taking whatever is present in the plankton at random. It seemed likely that a comparative study of the plankton indicator material and the food of the herring extending over several months in each of three years would be valuable as a contribution towards the solution of this



TEXT-FIG. 1.—The plankton indicator.

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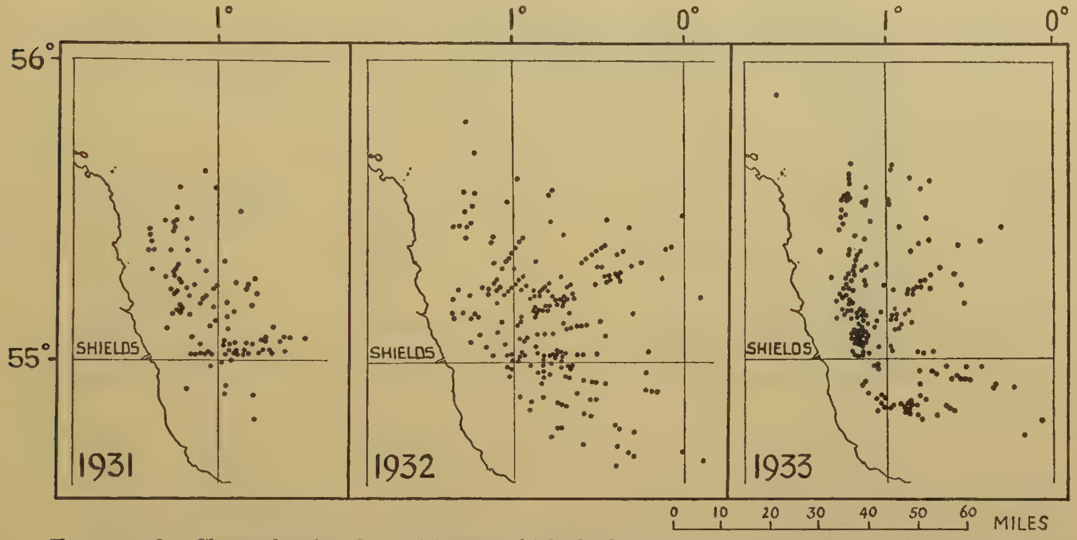
[1] Reports on its successful use by skippers have appeared in the trade papers (Balls, 1934 ; George, 1934).

important problem in the ecology of the herring, about which there still appeared some doubt.

It is with much pleasure that I express my most grateful thanks to Mr. Savage for his permission to use not only his published data, but his extracted individual results for the S.D. *Violet and Rose*, which he kindly placed at my disposal, to Mr. Lucas for kindly allowing me to incorporate the results of his 1931 plankton analysis, and to Professor Hardy for his valuable suggestions and criticisms. I should also thank Dr. Henderson, Mr. Rae and Mr. Macnae for their kind help in various ways.



Text-fig. 2.—Charts showing the positions at which plankton indicator samples were taken by herring drifters in the Shields fishery in the summers of 1931, 1932 and 1933, from Lucas (1936).

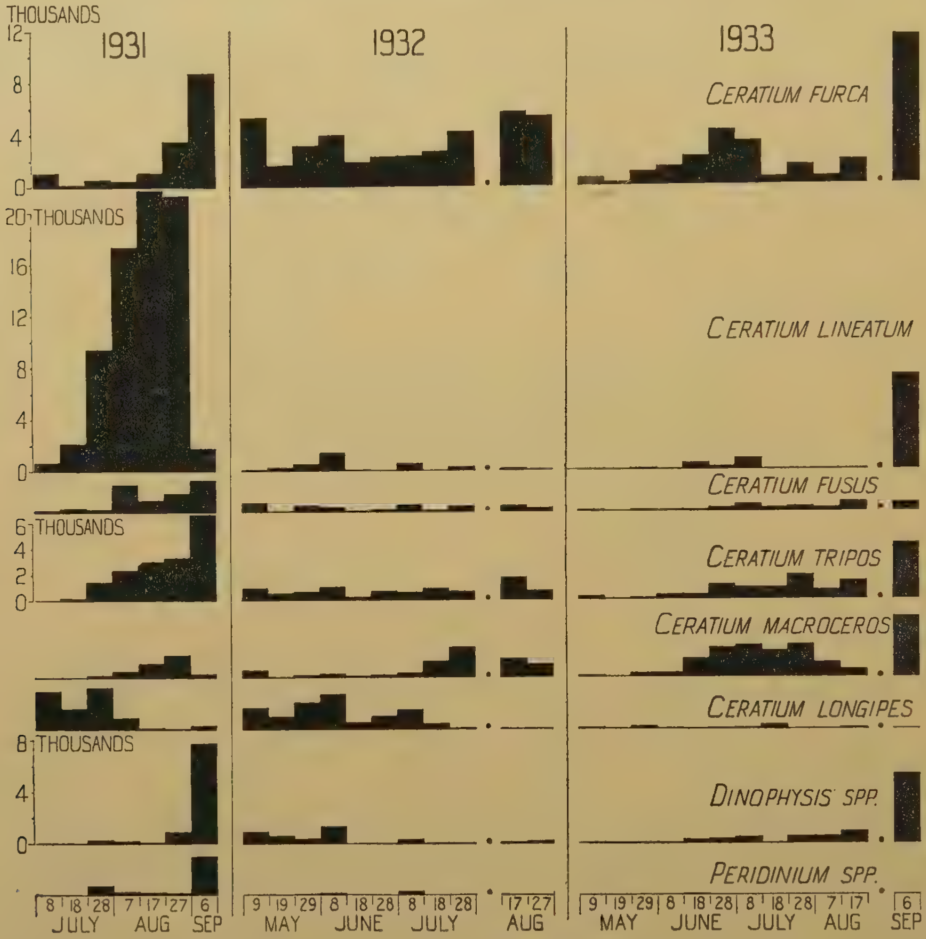
The Plankton of the Shields Fishing Grounds.

The plankton indicator, which is provided with diving planes like a paravane is so designed that it swims at a depth of between 7 and 10 metres when towed on the standard line provided—a depth approximately corresponding to that from which the herring are caught by the drift-nets. The summer herring fishery from Shields extends from the end of April to the beginning of September. The investigation did not begin until the end of June in 1931, but extended throughout the season in the years 1932 and 1933. The area considered in the present investigation is restricted to that which lies within a circle of 60 miles radius drawn with its centre at the mouth of the Tyne. All samples lying outside this area have been excluded. This, together with the fact that some of the samples used in the earlier investigation had been lost, reduced the total number of samples here considered to 430, distributed in time as follows :

1931, June 29th–September 8th .	104 samples.
1932, May 5th–August 24th .	184 ,,
1933, April 30th–September 1st .	142 ,,

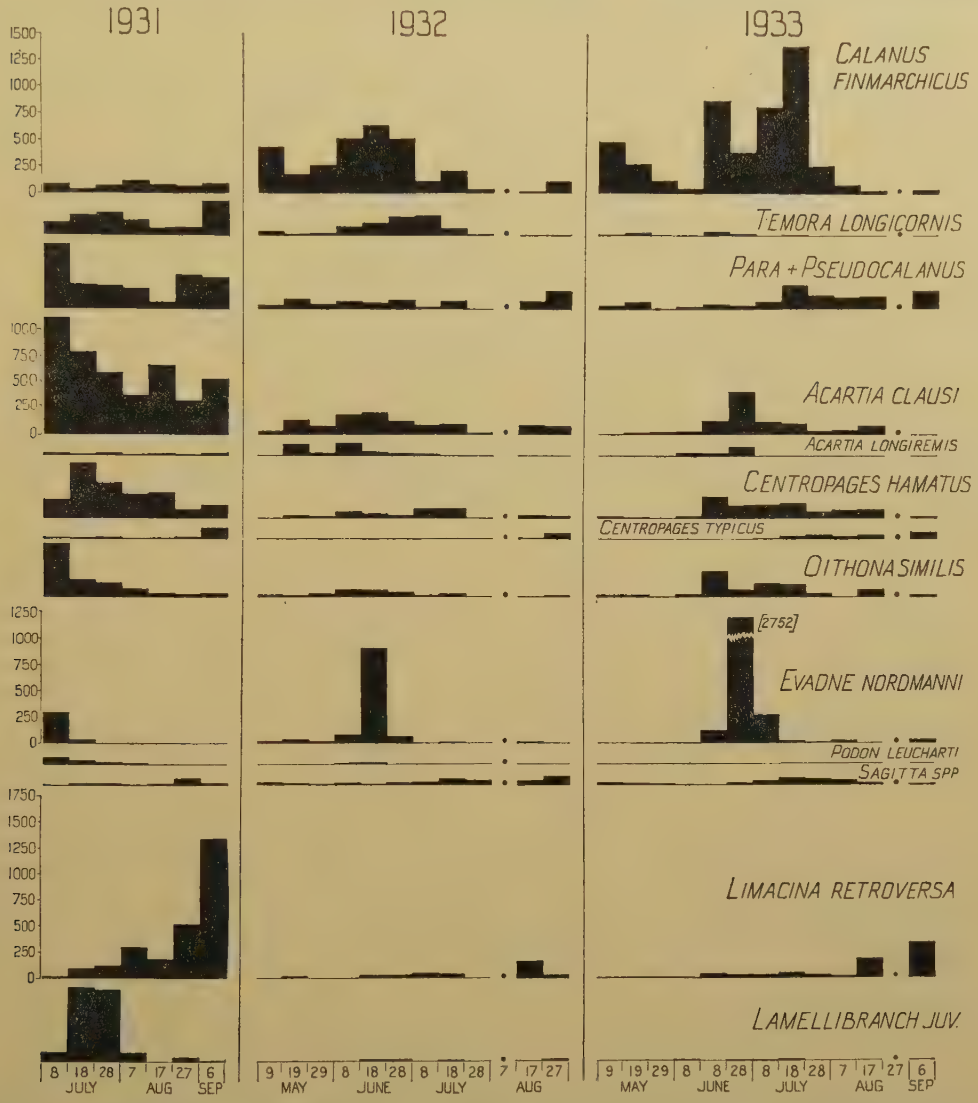
The distribution of the samples in space during the three seasons is shown in Text-fig. 2.

The samples were taken before the drifters shot their fleets of nets and thus were always taken at approximately the same time of the day, i.e. near sunset. This is important, for had the samples been taken at all times of the day and night, the varying vertical distribution of species showing vertical migrations would have greatly reduced the value of comparisons. This question has already been dealt with by Professor Hardy and Mr. Lucas (in Hardy, Henderson, Lucas and Fraser, 1936).



Text-fig. 3.—Histograms representing the average quantities of Dinoflagellates taken on plankton indicator discs in the Shields herring fishery during consecutive ten-day periods in the summers of 1931, 1932 and 1933. (The number of samples averaged in each period is shown in Text-fig. 6.) The dates given are those on which each ten-day period ended.

The method of collection on a gauze disc in an instrument towed at full speed and the wrapping up of the sample on the disc in calico in the preservative tin renders the condition of the plankton inferior to that collected by the tow-net. Whilst most organisms, including the crustaceans, are still identifiable, some of the more fragile ones such as medusae and Oikopleura have probably disintegrated and their absence from, or presence in small numbers in, the collection which has been stored for a long period after the original preliminary examination should not be regarded as significant. Against these limitations in method one must place the advantages of obtaining plankton samples from the actual vessels engaged



TEXT-FIG. 4.—Histograms representing the average quantities of the principal zooplankton forms taken on plankton indicator discs in the Shields herring fishery during consecutive ten-day periods in the summers of 1931, 1932 and 1933. (The number of samples averaged in each period is shown in Text-fig. 6.) The dates given are those on which each ten-day period ended.

in the fishery. Although from the standpoint of pure plankton research the samples may be incomplete, with the exception of Oikopleura they supply the information regarding the relative abundance in the plankton of all the organisms taken by the herring in this area and so supply the necessary material for a comparison.

On the re-examination of the 1932 and 1933 data it was not infrequently found that the total numbers for a group of organisms, e.g. Dinoflagellates, were less than those recorded by Mr. Lucas in his earlier analysis. Undoubtedly some loss, particularly in the Dinoflagellates but also in the Copepoda, must have occurred in the handling and re-handling of the material. Whenever the total in my analysis was less than that of Mr. Lucas his was taken and the numbers of the different constituent Dinoflagellate species found by me were increased by a proportionate amount to bring them up to the total as recorded by Mr. Lucas and so be comparable with his data for 1931. The same procedure was adopted with the Copepoda where there appeared to be obvious signs of loss.

The data from the analysis are presented as averages for ten-day periods throughout each season; these periods were chosen to correspond exactly with the ten-day periods taken by Savage in his herring food examinations. In the graphic representations of the results the dates given throughout are those for the last day of each ten-day period.

Phytoplankton.

Diatoms are exceedingly scarce in the collections, since the samplings commenced after April, i.e. after the spring outburst of diatoms. The phytoplankton consists almost entirely of dinoflagellates of which species of Ceratium are most dominant; *C. furca* (Ehrenberg) Dujardin, *C. lineatum* (Ehrenberg) Cleve, *C. tripos* (O. F. Müller) Nitzsch, *C. longipes* (Bailey) Gran, *C. fusus* (Ehrenberg) Dujardin, *C. macroceros* (Ehrenberg) Cleve and *C. horridum* Gran. Considerable variation in the abundance of these species was shown in the different years. Whilst we have no September samples for 1932, most species showed a maximum in September, 1933 (*C. furca, C. lineatum, C. tripos* and *C. macroceros*), and two species a maximum in September, 1931 (*C. furca* and *C. tripos*).

C. furca was generally more abundant in 1932 than in 1931 and 1933. *C. lineatum* was exceedingly rich in 1931 reaching its great maximum in August and became very scarce in the following two years, except for a smaller maximum in September of 1933. *C. fusus* was scanty throughout, but slightly more numerous in 1931 than in the other two years. *C. tripos* was also more abundant in 1931 than in the other years. *C. macroceros* was more abundant in 1933. *C. longipes* was extremely scarce in 1933, but was taken in moderate numbers in July, 1931, and from May–July, 1932. *C. horridum* was only taken occasionally. The relative abundance of the different species together with Dinophysis and Peridinium spp. in the different periods are shown in Text-fig. 3. Dinophysis showed a maximum in early September, and Peridinium spp. were extremely scarce except in September, 1931; the low numbers of these forms, however, compared with those of Ceratium should not be regarded as significant as they are more easily lost through the meshes of the gauze.

Zooplankton.

The Copepoda are the dominant animals in the samples, the following species being represented :

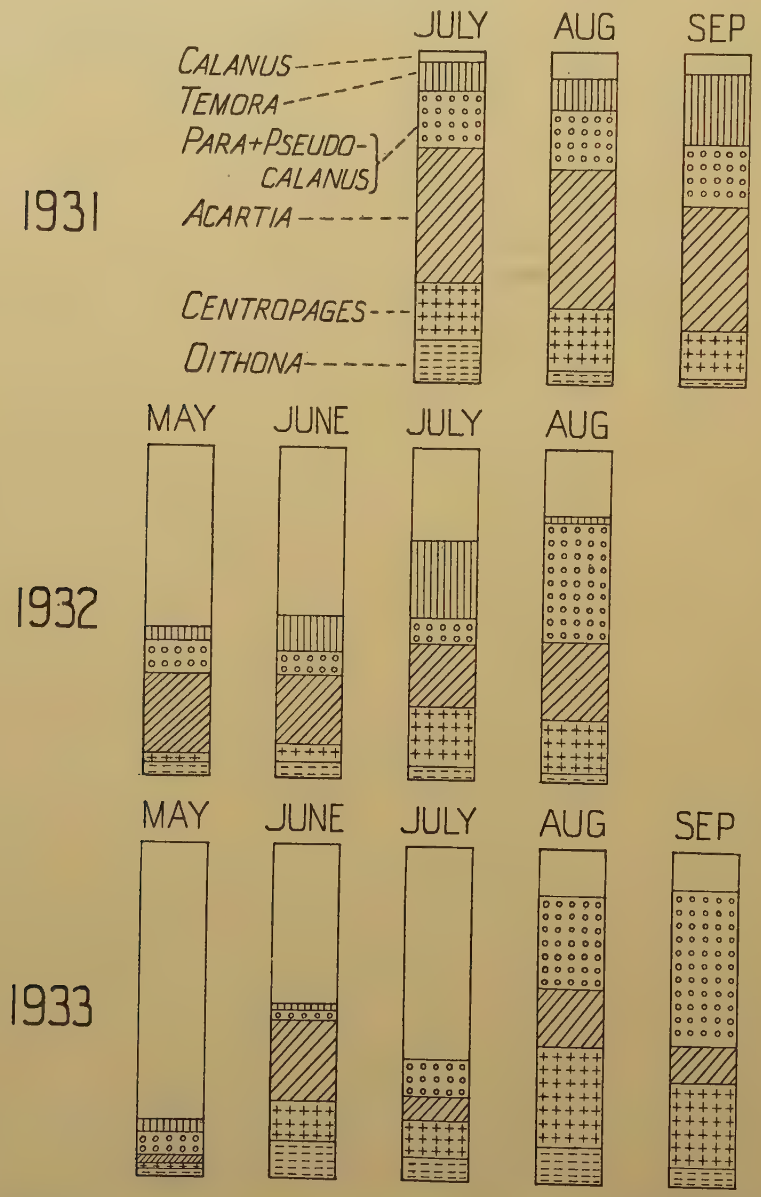
Calanus finmarchicus (Gunn).
Paracalanus parvus (Claus).
Pseudocalanus elongatus Boeck.
Temora longicornis (Müller).
Centropages hamatus (Lilljeb.).
Centropages typicus Kröyer.
Acartia clausi Giesbrecht.
Acartia longiremis (Lilljeb.).
Anomalocera pattersoni Templt.
Oithona similis Claus.

The relative abundance of the more important species in the different periods together with other zooplankton forms is shown in Text-fig. 4. *Calanus* greatly outnumbers the other copepods in 1932 and 1933, but was comparatively scarce in the later part of 1931 ; on the evidence of Savage's herring food investigations it would appear that *Calanus* must have been very abundant in the plankton in the earlier part of 1931 before our sampling commenced. The late persistence of the bulk of the Calanus in the Shields area in these years has been attributed by Lucas (1936) to the increasing inflow of northern Atlantic water into the North Sea year by year during this period. The other striking features of the Copepod distribution are the extreme scarcity of *Temora longicornis* in 1933 and the great abundance of *Acartia clausi* in 1931. The relative abundance of Temora in the latter part of 1931 at a time of scarcity of Calanus is of importance in relation to the herring, and will be further discussed in a subsequent section. In each year *Centropages typicus* occurred in smaller numbers than *C. hamatus*, and appeared later in the summer. *C. hamatus* was more abundant in 1931 than in the two following years. *Anomalocera pattersoni* is not shown in Text-fig. 4 ; it occurred in only very small numbers in August, 1931, and July, 1933. The relative proportions occupied by the different species within the total copepod population are shown as percentages of the totals for each month in the histograms in Text-fig. 5.

The Cladocera are represented by *Evadne nordmanni* Lovin and *Podon leuckarti* G. O. Sars. The occurrence of the latter in the samples was very rare indeed, and if present, its numbers were always very small. *Evadne nordmanni* occurred in large numbers, but only for a comparatively short period each year. Its maximum in 1932 occurred on June 17th, and in 1933 on June 22nd ; in 1931 no samples were obtained before July, but judging from Savage's herring food data it probably reached its maximum in that year in late June. (Jorgensen (1936) gives its maximum period as occurring mostly in June.)

Decapod larvae were very poorly represented in the samples.

The condition of the plankton on the indicator discs after long storage did not allow of specific identifications being made for Sagitta.



TEXT-FIG. 5.—Histograms showing the varying percentage proportions occupied by different Copepoda species within the total copepod population for different months as sampled by the plankton indicator in the Shields fishery.

The pteropod *Limacina retroversa* Flem. occurred in increasing numbers from August onwards in 1931, reaching its maximum on September 2nd; in the following two years it was present only in small numbers, but again being relatively more abundant at the end of the season.

Lamellibranch larvae were quite abundant in July, 1931, but extremely scarce in the following two years.

The small number of Oikopleura encountered in the samples (not shown in Text-fig. 4) should not be regarded as significant; whilst Savage (1926) has shown that they are more abundant in water layers deeper than that fished by the indicator, it is likely that these fragile organisms together with medusae have disintegrated in the process of sampling and storage.

Other Zooplankton forms: Amphipods, Mysids, Euphausiaceans, fish larvae and fish eggs were only occasionally encountered in the samples and their numbers were always very small.

Comparison of the Plankton with the Food of the Herring as Recorded by Savage (1937).

The question as to whether the herring feeds by selection, i.e. by a definite act of capture of certain favourite organisms or whether it feeds by swimming through the water and filtering out the plankton organisms encountered at random by the action of the gill-rakers was discussed by Hardy (1924). He reviews the opinions of former naturalists, some of which held one view and some the other, and upon the evidence of his own investigations comes to the conclusion that the herring feeds by a definite act of selection. Later Savage (1926) describes the plankton of the Shields herring grounds as found on a cruise made in July, 1922, and compares the results of the plankton analysis with the herring food recorded by Hardy. After discussing the occurrence of Calanus and Temora in the two sets of data (Temora at this time being predominant in both) he says: "It is noticeable that all the other species, which are of smaller size, were present in greater proportion in the plankton than in the food. Hardy states that the herring selects its food and these figures appear to confirm his conclusion." Bigelow (1926, p. 101), after discussing the menhaden, writes: "The herring and alewife, with coarser sieves, subsist chiefly on organisms with a longest dimension of at least 0·5 millimetre (copepods and larger animals), which they select individually, and not by swimming open-mouthed, as the menhaden does."[1]

In a subsequent paper, however, Savage (1931) makes a special study of the food of the herring in relation to the plankton obtained on a series of cruises to the Shields fishing area and writes as follows:

> "Much has been written on the question as to whether herring feed by selection, or indiscriminately on anything which comes their way, but there is little unanimity amongst the different workers (see Hardy, 1924, p. 27). Our view is that selection of individuals takes place when the size and abundance of the latter make it worth while from the point of view of the labour and time involved in securing enough to satisfy the appetite. At other times, there is probably what might be called 'mass' selection, that is, the herring feeds *discriminately* on

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[1] See also Battle, Hunstman and collaborators, 1936.

> the mass of plankton in the water. Certain kinds of plankton, e.g. diatoms, coelenterates, *Phaeocystis*, etc., might be distasteful and cause the herring to move away in search of more palatable food.
>
> " This is borne out by the results of the present work. Whenever a food species was at a maximum in the plankton, it was invariably present in the stomach in maximal numbers also, e.g. *Calanus*, *Temora*, *Oikopleura*, *Sagitta*. Hardy commented on the comparatively poor representation in the stomach contents of the smaller copepods such as *Pseudocalanus* and *Paracalanus*, which were numerous in the plankton, and considered that the herring probably do not trouble to take them so long as the larger species, *Calanus* and *Temora*, are abundant. In 1926 there were also many fewer of these small forms than the larger in the stomachs, while in the plankton collections they were much more abundant than *Calanus* and *Temora*. It must, however, be borne in mind that the estimates of the numbers in the plankton were in both cases based on collections with a net, the meshes of which were 60 to 1 linear inch. With such small meshes the smaller copepods would be caught in proportionately greater numbers than the larger ones ; an increase of mesh size results in a greater proportion of the larger species."

After giving examples of the marked differences found in the proportions of different species of copepods taken in nets of different mesh, i.e. the Hensen net with 60 meshes to 1 inch, and the Nansen net with 40 meshes to 1 inch, he concludes as follows :

> " We cannot therefore say definitely that because a net made of a certain mesh catches more small copepods than large ones, that there are more of the former in the plankton than the latter, and that the herring is ignoring the most abundant copepods in its quest for food. In a way the herring can be considered as a catching machine in the same way as are plankton nets, and may lose some of the smaller elements of the food by way of the gill-rakers."

The gauze used for the plankton indicator discs has a mesh of 60 threads to the inch, i.e. the same as that of the Hensen net used in Mr. Savage's investigations, and Hardy (p. 154 in Hardy and collaborators, 1936) has shown that this does actually correspond approximately to the number of gill-rakers to the inch in the herring. Thus it would appear that Mr. Savage's fear that the plankton catch of a herring, if the herring is to be considered as a plankton sampling machine, could not be compared with the catch of a net of 60 threads to the inch, is removed.[1]

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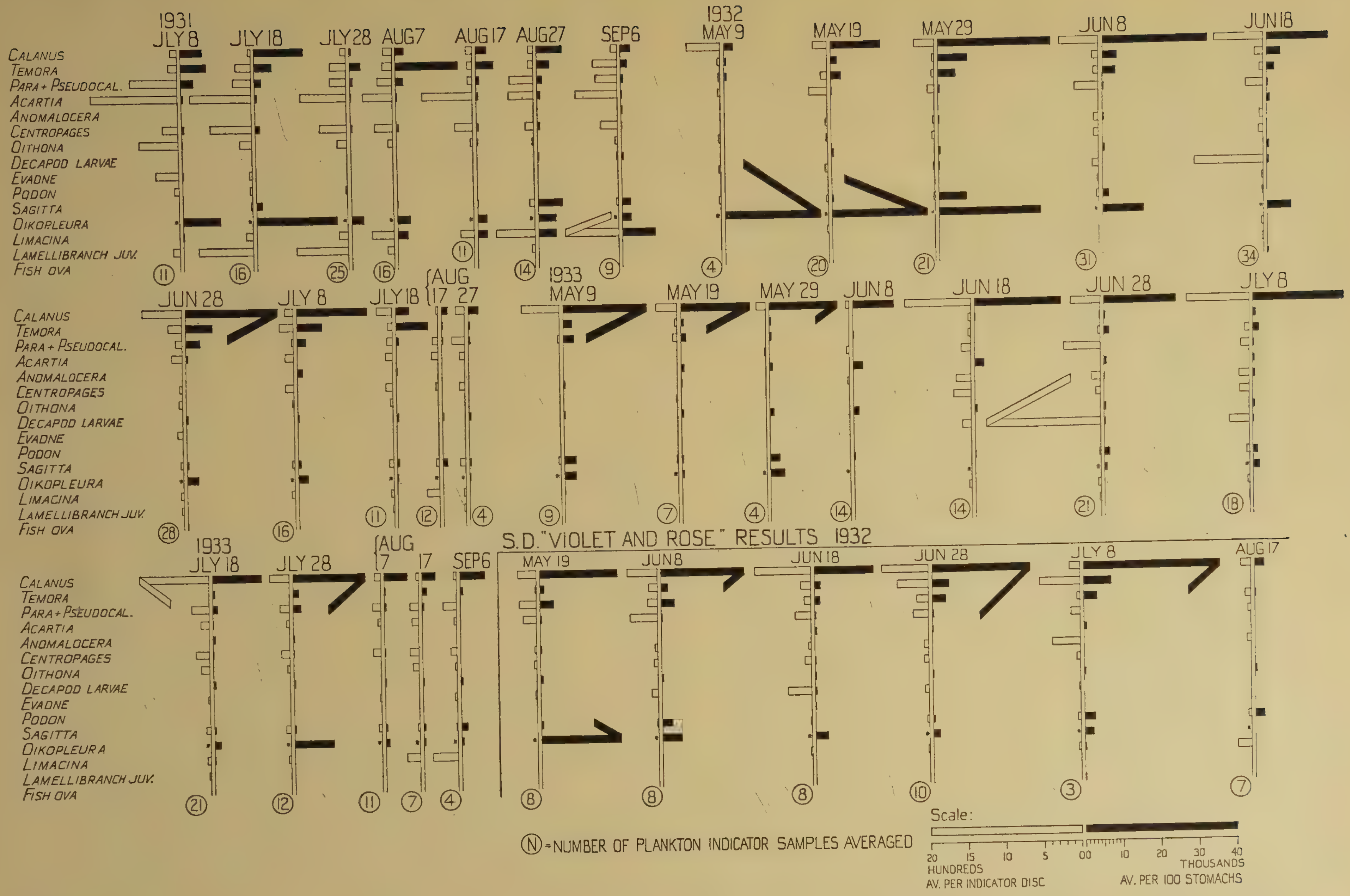
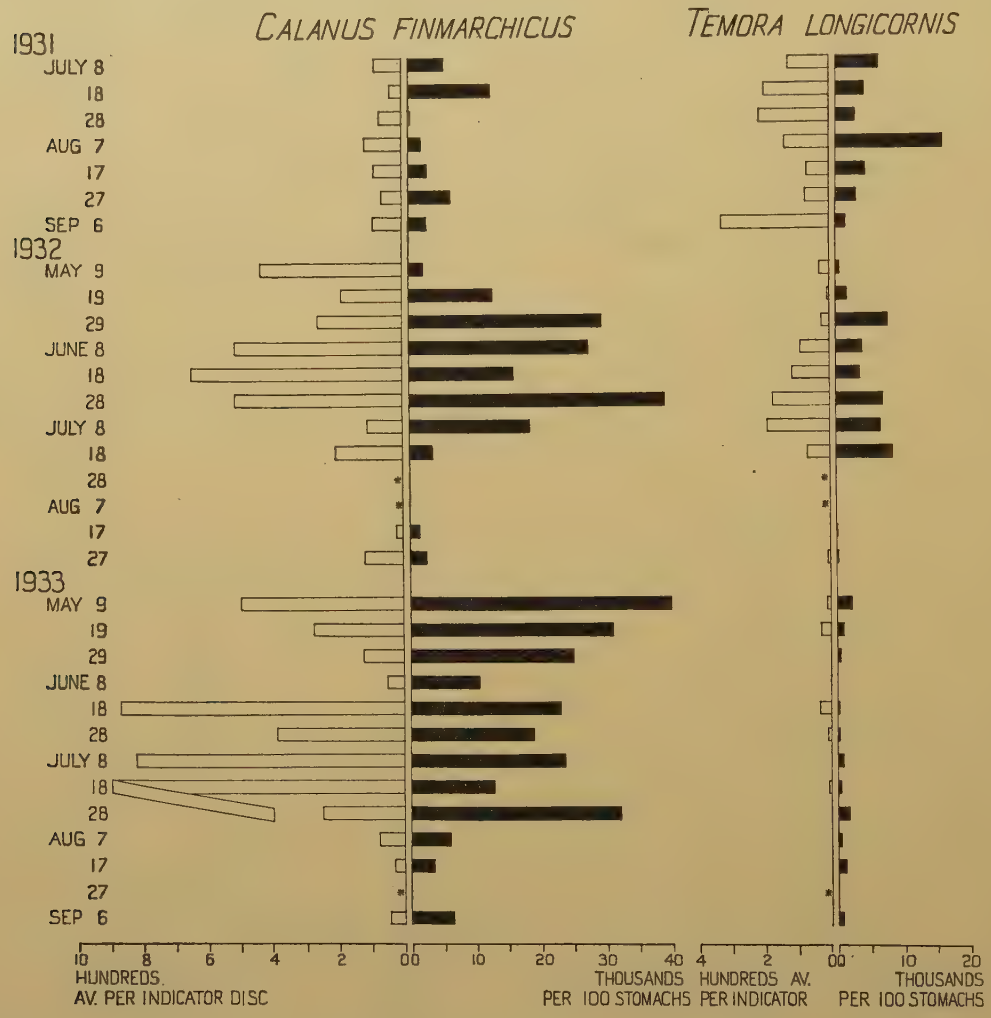
[1] Professor Hardy has recently made some counts of the number of gill-rakers per ½ inch in twelve herring of various lengths. The gills were cut out, laid flat and fully expanded, and the number counted per ½ inch along a line at right angles to the gill-rakers. There is some variation in the number ; in general, as would be expected, there are more per ½ inch in the smaller fish than in the larger. The average number is 31·5 per ½ inch, which compares closely with the meshes of the Hensen net and the plankton indicator gauze (30 per ½ inch). The numbers of gill-rakers were as follows :

Length of fish.	Gill-rakers per ½ inch.	Length of fish.	Gill-rakers per ½ inch.
22 cm.	32	24·5 cm.	30
22 ,,	36	25 ,,	26
22·5 ,,	34	27 ,,	26
23 ,,	35	27·5 ,,	29
23 ,,	35	27·5 ,,	32
23·5 ,,	35		
24 ,,	28	Average	31·5



TEXT-FIG. 6.—Comparative histograms arranged to show the relative abundance of plankton animals in samples taken by the indicator (open histograms) opposite those representing the relative abundance of the same species as found by Savage (1937) in the stomachs of herring caught during the same ten-day periods in the same fishery during 1931, 1932 and 1933. In addition to twenty-nine such periods there are shown six relating to data supplied by a single drifter, the *Violet and Rose*, in the summer of 1932. Plankton values for Oikopleura are omitted (see p. 243).

In Text-fig. 6 a series of comparative histograms are arranged to show the relative abundance of animals in the plankton as shown by the plankton indicator samples, side by side with histograms to show the relative abundance of organisms found by Savage in the stomachs of herring during each of the same 29 ten-day periods. Only those periods have been included for which there are more than four plankton samples; the average number of samples per period is 15. The herring food is that found by Savage per 100 stomachs. The plankton histograms



Text-fig. 7.—Histograms (open) representing the numbers of *Calanus finmarchicus* and *Temora longicornis* taken per average plankton indicator disc compared with others (blacked-in) representing the numbers of the same species as found by Savage (1937) per 100 herring stomachs during the same ten-day periods.

are left open and shown to the left; the herring food histograms are blacked in and shown to the right. In addition there are also shown at the bottom right-hand side of the figure similar comparisons, but for data supplied by a single drifter, the *Violet and Rose*, using the indicator at the same time as supplying Mr. Savage with samples of stomachs during six ten day periods during 1932. He very kindly provided the latter data, which were not so separated in his published paper. We should clearly not expect there to be an exact agreement, or even always a general agreement, when the plankton samples may not have been taken in even approximately the same part of the area from which the fish were taken. We know how patchy the plankton may be in its distribution. Nevertheless, when considering all the 29 periods together, as well as the 6 more special *Violet and Rose* samples, we do see a number of striking features in the plankton and herring stomach comparisons.

There is usually either a good correspondence between the proportions of Calanus in the herring stomachs and that in the plankton, or the proportion in the stomachs may be very much greater than that in the plankton. The same is generally true of Temora, but to a lesser extent. This correspondence between the number of Calanus and Temora in the plankton and stomachs is shown more clearly in the histograms devoted exclusively to these forms shown in Text-fig. 7 on a somewhat enlarged scale. When Temora is present in any quantity in the plankton it is taken by the herring; it was very scarce in 1933 in both the plankton and herring stomachs.

If Calanus and Temora were considered alone it might be said that there was little evidence of selection, but turning to the relative proportions of other organisms (i.e. in Text-fig. 6) we see a very different picture; Acartia, Oithona, Cladocera and Lamellibranch larvae are always present in larger proportions in the plankton than in the stomachs, and the same is true of Centropages except in two insignificant instances (periods ending May 9th and 19th, 1933). Frequently Centropages is present in the plankton in quite appreciable quantities, yet it is hardly ever present at all in the stomachs. The reverse is true of the larger copepod Anomalocera, which is frequently found in the stomachs but has only rarely been taken on the plankton indicator disc.[1] All these facts taken together strongly confirm the view that the herring does select the larger forms Calanus, Anomalocera and Temora by a definite act of capture, and tends to ignore the smaller forms. The fact that Oikopleura, whilst often an important element of the food, was not recorded in the plankton is not regarded as significant for the reasons given on p. 243.

Further valuable evidence is available from the data regarding the pteropod Limacina and the chaetognath Sagitta. The remarkable similarity in the increase in the number of Limacina in both the plankton and herring stomachs as the season advanced at the end of the 1931 fishery has been remarked upon by Lucas (1936) and Savage (1937). There is no such close agreement in 1932 or 1933. Curves of the abundance of Limacina in the plankton and the stomachs for the three seasons are compared in Text-fig. 8. Now in the case of Sagitta, also shown in Text-fig. 8, we see just the same thing: a close correspondence in the latter part of the 1931 season, but not in the other two years, when, except for a short period in May there are distinctly higher proportions in the plankton than in the stomach contents. Whilst the number of Limacina in the plankton in 1932 and 1933 was

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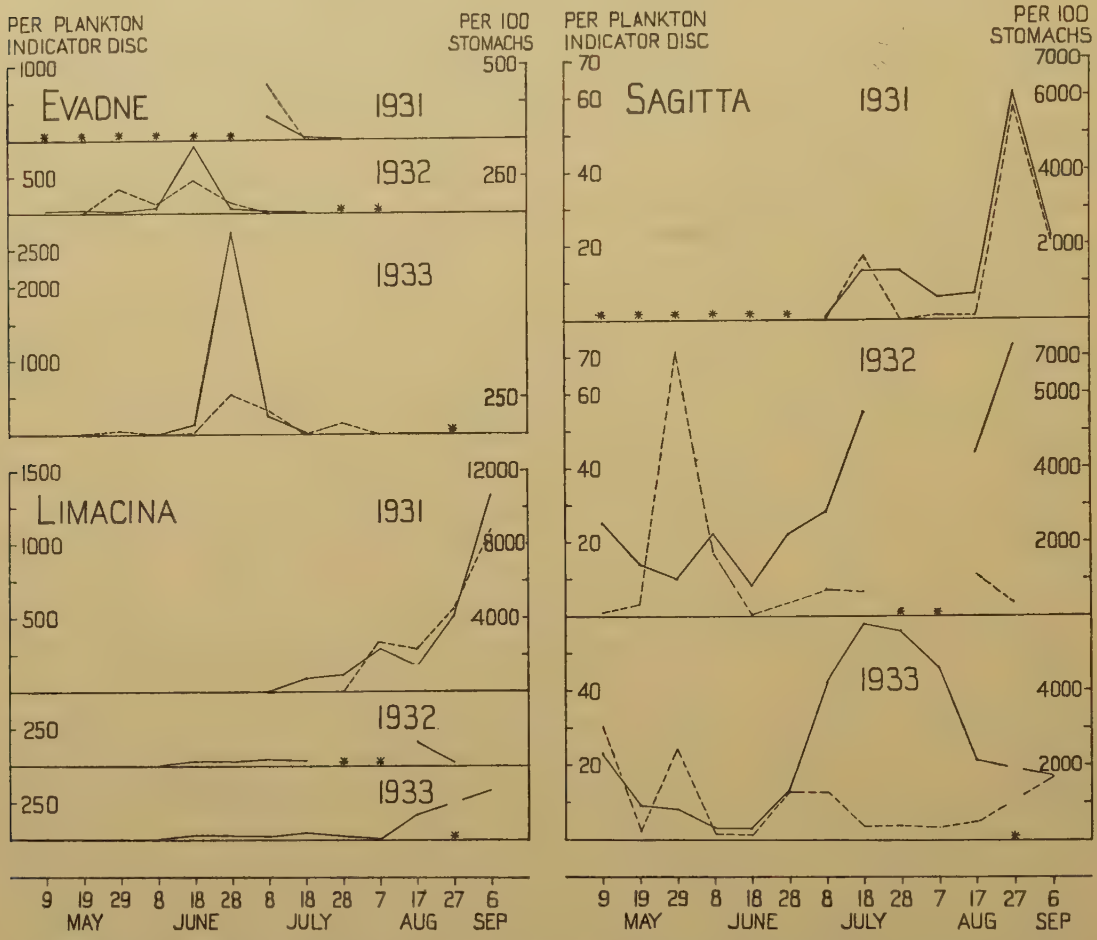
[1] It has been suggested by some authors that *Anomalocera patersoni* is almost entirely a surface form and, if this is so, the plankton indicator might have missed it entirely at a depth of 7–10 metres. Russell (1927), however, shows it may occur in fair numbers down to 10 metres and on one occasion had its maximum numbers at 20 metres.



TEXT-FIG. 8.—Graphs comparing the numbers of Evadne, Limacina and Sagitta in the plankton as shown by the plankton indicator (continuous line) and in herring stomachs as found by Savage (1937) in the same ten-day periods (broken line) during 1931, 1932 and 1933. An asterisk indicates that no samples, or too few, were taken. The numbers of Limacina taken by the herring in 1932 and 1933 are too small to be shown as a graph on the scale adopted: the highest number being 92 in 1932 and 129 in 1933.

very much less than in 1931, this is not true of Sagitta. The latter part of 1931 was marked by a singular scarcity of Calanus in the plankton, and it is difficult to escape the conclusion that the herring, when short of the food it usually prefers, turns to feed upon Limacina and Sagitta in larger numbers. It will be remembered that it was just in this period of 1931 that Lucas (1936) found that the positive herring-Calanus correlations for the Shields area broke down.

In Text-fig. 8 is also shown the relative abundance of the cladoceran Evadne in the plankton and stomachs. They are never taken in large numbers by the herring, but the peaks of abundance in the two series show a striking correspondence, although its maximal number in the stomachs is very small indeed in comparison with that in the plankton. It appears either that it may be taken in small numbers indiscriminately with the selected larger food elements just during its great maximum in June, or that only during this time of abundance is the herring likely to concern itself with them.

SUMMARY.

1. 430 plankton samples which were taken by several herring drifters using the Hardy Plankton Indicator in the Shields fishing area during the summer seasons of 1931 to 1933 are analysed to show the main changes in the plankton during those seasons.

2. A comparison is made between the proportions of the different zooplankton organisms found in the plankton and the proportions of these recorded by Savage (1937) in the stomachs of herring obtained from drifters working in the same area and during the same time. The comparisons are made for 29 ten-day periods in the seasons 1931 to 1933, and in addition for 6 ten-day periods relating to a single drifter which obtained both plankton and stomach samples at the same time in 1932.

3. The comparisons in 2 provide evidence that the herring feeds by selecting certain organisms by individual acts of capture and not by swimming open-mouthed to strain out the plankton indiscriminately :

(*a*) Calanus and Temora in the stomachs either correspond fairly closely to the proportions in the plankton or they may be in very much higher proportions. The latter is always true regarding Anomalocera.

(*b*) Acartia, Oithona, Cladocera and Lamellibranch larvae are always in larger proportions in the plankton than in the stomachs ; this applies also to Centropages with two insignificant exceptions.

(*c*) There is a close correspondence between the numbers of Limacina and Sagitta in the plankton and stomachs in the latter half of the 1931 season, but not during 1932 and 1933, when the numbers in the stomachs were insignificant ; during the former period there was a great scarcity of Calanus in the plankton.

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[*Hull Bulletins of Marine Ecology, Vol. I, No. 6, pp. 255–275, Plates CXXVI–CXLIX, July, 1944**.*]

ECOLOGICAL INVESTIGATIONS WITH THE CONTINUOUS PLANKTON RECORDER:

THE ZOOPLANKTON (OTHER THAN COPEPODA AND YOUNG FISH) IN THE SOUTHERN NORTH SEA, 1932-37

BY

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AND

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* Publication delayed through both authors being on active service in H.M. Forces.—Editors.

INTRODUCTION.

THE object, plan and methods of the plankton recorder survey have been discussed in 'Bulletin' No. 1 (Hardy, 1939). For the first five and a half years, 1932–37, the survey was confined to the southern part of the North Sea, and reports on the phytoplankton (Lucas, 1940) and the Copepoda (Rae and Fraser, 1941) have already been published. The following account deals with the rest of the zooplankton taken in that period, except for the fish eggs and larvae which are being treated together with those for 1938–39 in a report being prepared by Dr. Stubbings.

The present paper has been both delayed and curtailed by the absence of the authors in the services.

The first five and a half years was a trial period, the forerunner of the wider and more detailed survey begun in 1938. During this early phase, when the staff were also engaged on the plankton indicator work (see Hardy, *loc. cit.*) the identification of species was limited to certain important diatoms and Copepoda; time only permitted the recording of other zooplankton under generic or group names. This is the most serious limitation to the present report; the determination of groups dealt with is not carried further than the following categories: the *genera* Sagitta, Limacina, Clione, Evadne, Podon and Oikopleura, and the wider groups Echinoderm larvae, Lamellibranch larvae, Decapod larvae, Caprellid Amphipoda and Squilla larvae. Further, the distribution of the Mysidacea and Euphausiacea has not been dealt with because it has been shown that their marked vertical migration makes results from the recorder method difficult of interpretation for both groups. Unfortunate as these limitations are, it is nevertheless felt that this brief report, when taken with the details of the phytoplankton and Copepoda already published, will be of value in giving a general picture of the changing plankton community in these years, and also in providing some basis for comparison with the more detailed work carried out in the extended survey of the whole North Sea begun in 1938 (and which will be continued, it is hoped, after the war).

Reference should also be made to 'Bulletin' No. 1 for the various changes which have been made in the recorder technique during the survey. A map of the recorder routes and a complete summary list of records giving particulars of dates, times, sea and weather conditions will be found in 'Bulletin' No. 2 (Anon., 1939). All the records have been analysed for zooplankton except certain ones taken for phytoplankton only (indicated by "P" in this list).

Throughout the report the different routes will be referred to by the letters used in the summary list just mentioned: *i.e.* "C" for the Hull–Copenhagen, "B" for the Hull–Bremen, "E" for the London–Esbjerg, and "R" for the Hull–Rotterdam route.

Limitations of Sampling Methods.

For a general discussion of this matter and a section dealing with the catching power of the recorder the reader is again referred to 'Bulletin' No. 1.

Three important questions must be considered when interpreting the results shown by this method of taking continuous series of samples in straight lines across the sea at a uniform depth:

(1) What numerical differences along the lines are biologically significant, *i.e.* what differences are due to an actual uneven distribution of the plankton and what due simply to the errors inevitable in "linear" sampling at sea and sub-sampling in the laboratory.

(2) To what extent does the vertical migration of different animals interfere with an estimate of their spatial distribution?

(3) Are the series of lines giving a representative picture of the changes which are going on over the whole area, or are there important events being missed between the lines of observation?

The first of these has already been discussed at length by Rae and Fraser (1941, p. 178) when dealing with the Copepoda. After discussing two distinct sources of error due to random sampling, firstly by the machine in the sea and secondly in the process of laboratory estimation, they go on to say:

> "It will be seen that these [records] show a number of well-marked changes in concentration both in space and time, which are too large to be accounted for by any chance distribution, and further are shown by a number of successive but independent estimations. These are the major ecological variations that the survey was designed to reveal. Superimposed on these gross changes, there are, however, minor fluctuations which give the graph a wavy appearance. These may, of course, well be due to genuine minor patches or swarms only a mile or two in breadth, but it appears possible that they are artefacts produced by the errors entailed in the two random selections."

The same applies to the present work, but here the errors of sampling have less weight than in the Copepoda report, where the results were shown as graphs. Here the results are approximated to a series of figures and/or symbols which cut out the smaller and probably non-significant differences. Further, more emphasis in this report is placed on the broader seasonal changes than on the detailed spatial distributions of each month. In showing these seasonal changes year by year the average values for the whole of each line have been used, so that small errors due to random sampling should to a large extent cancel out. The random errors due to laboratory technique are referred to below under methods of estimation.

Regarding the second point, since the recorder is towed at a constant depth of 10 metres, it might be expected that more animals would tend to be taken at night than in daylight. Clearly no set of samples limited to one depth can give direct knowledge of vertical migration; but it is important to consider whether this factor is producing an erroneous picture of the zooplankton distribution. To test this, the numbers of a given organism caught over a distance of 50 miles before sunset were compared with the numbers caught over 50 miles after sunset, and likewise before and after sunrise; so large a distance was taken in order to minimize as far as possible the effects of irregular horizontal distribution. Since the average speed of the ships is about 10 knots the comparisons involve periods of five hours before and after sunset and sunrise, periods in which the major changes in vertical distribution may be expected to occur. Only the Mysidacea and Euphausiacea showed a marked correlation between their distribution and those parts of the line taken between sunset and sunrise; for this reason, as mentioned in the introduction, all detailed consideration of their distribution is omitted from this paper. Of other forms, none showed any significant correlation by this admittedly indirect method. A discussion of the same problem will be found in Rae and Fraser's (1941) report on the Copepoda. These tentative results can in no way be taken as evidence against the occurrence of vertical migration, but it does seem clear, as Rae and Fraser found, that its effects are *masked* by the even greater fluctuations in spatial distribution. It is with these major distributional changes that this survey is concerned. The problem of vertical migration will be returned to in later reports.

The third question reveals an undoubted limitation to the value of results from these first five and a half years of the survey. The radiating lines became at their eastern ends so far apart that some events of importance may well have occurred between them, and passed unrecorded by our system. The E line begun in 1937, and the extended survey of 1938, with its new lines converging towards the east and intersecting the former lines, have gone far to overcome this defect. This early survey cannot present a complete picture, but it does for the first time attempt to show the kind of changes which are taking place in cross-sections through the plankton community month by month for a number of years over a considerable portion of the area. There are gaps in the picture which it is dangerous to attempt to fill by speculation based upon the too distant adjacent lines. Such a limitation to this pioneer period of the survey must be recognized.

METHODS OF ESTIMATION.

All quantities of plankton have been calculated with reference to a water-tunnel aperture of ½ in. square section on the experimental evidence (Hardy, *loc. cit.*, p. 43) that the volume of water passing through the recorder is proportional to the area of the aperture. The aperture was changed from ¾ in. square to ½ in. square section in May, 1937, at the time when the silk/mileage ratio was increased to approximately 5 miles per section. This reduction of all quantities in reference to the smaller aperture has also been adopted in the other reports for this period, so that all the data will be comparable with the results of later surveys.

The larger zooplankton forms, *i.e.* Sagitta, Euphausians, Mysids, Amphipods and Decapod larvae have usually been counted with the naked eye, while the smaller forms, such as Echinoderm larvae, Lamellibranch larvae, Oikopleura, Cladocera and Limacina have been estimated by counts made with the traversing microscope (see Hardy, 1939, p. 32 for a description of this). Sagitta and Decapod larvae, when very small, have been estimated with the traversing microscope, while conversely the Limacina, when very large, have been counted with the naked eye. In the naked-eye counts all the organisms present on each division or 10-mile block of silk have been counted, while the numbers found in one microscope traverse on each division have been multiplied by a factor of 20 (*cf.* Rae and Fraser, 1941, p. 175), to give the totals present on each division of silk. This procedure alone was adopted during the earlier part of the survey when the ratio (*i.e.* the number of miles represented by each section of silk) was from 1·5 to 2·5 miles. In 1936, however, the rolls were cut up into 10-mile blocks, and one complete staggered traverse was then adopted in counting the total organisms on each block. Here the numbers counted in the traverse were multiplied by 20 times the number of sections per 10-mile block. Finally when the ratio was increased to 5 miles (approximately), one half traverse was made on each section and the factor changed to 20 × 2 (approximately).

The naked-eye counts of the larger and less numerous organisms should give within very narrow limits a true estimate of the numbers caught. Counts made by examining a sample of the plankton and then multiplying by a factor provide only small random variations from the true value for the catch unless the plankton is very unevenly spread on the gauze. While the zooplankton tended sometimes to be transversely displaced on the rolls, it was rarely clumped together in a way that would give anomalous results.

FORM OF PRESENTATION.

The distribution of each form is shown in a series of charts in Plates CXXVI–CXLIX ; for Limacina and Sagitta there is one for each month, but for some of the others there are only selections, those with little or no data being omitted for economy. Occasionally two or three months have been combined.

Graphs which were used in the earlier papers to record the fluctuating quantities on each line have not been adopted here. Each route has been divided into blocks of ten miles both as a convenient method for charting the results, and for more ready comparison with the data from the 1938–39 extended survey.

Two methods have been adopted for showing quantities. For the various larvae, Cladocera, Amphipoda and Oikopleura, symbols are used, each covering a certain range in numbers (*e.g.* scale in Plate CXLV). Those for each organism (apart from the Sagitta, Decapod larvae and Caprellidae) refer to the numbers present *per mile* per block, *i.e.* one tenth of the number estimated for each block. The Sagitta, Decapod larvae and Caprellidae, being on the whole less numerous, have been represented as *numbers per block.*

For Sagitta and Limacina both symbols and numbers have been used. Sagitta numbers refer to the nearest ten or hundred on each block. Limacina, although rarely occurring in high numbers in the southern area, has been plotted as numbers per mile per block so as to compare with those of 1938–39 for the whole North Sea. A scale of values for symbols or numbers is given on each series of charts. The date of each record is shown at its eastern end ; when it extended over more than one day the date is that on which the greater part was taken.

In summarizing the varying plankton through the months of each year histograms have been used, with the exception of a graph for Sagitta which, being present on the majority of the records, shows more continuity (Text-figs. 1–3). Each ordinate value represents the mean number of the organism per block over the sampled part of the standard route. Records with a mileage less than one half of the normal have not been shown except where a mean value, obtained artificially by dividing the total quantity by the number of blocks on the *whole* standard line (just as if it had been fully sampled), was higher than those for adjacent months. Such exceptional records have been indicated by open histograms.

DISTRIBUTION OF THE ZOOPLANKTON.

It is not thought necessary to repeat in long description the details which are clearly shown on the charts. The plates themselves form the bulk of the report and give the most concise description of the distribution. The text will discuss and draw attention to only the more important features, particularly the seasonal and yearly differences which can be discerned throughout the period reviewed ; these changes in time are again mainly shown in graphical summary form in Text-figs. 1–3. The correlations between the fluctuations in distribution and the hydrological conditions will be discussed in a later ‘ Bulletin.’

Sagitta (Plates CXXVI–CXXXI).

Specific determination only became possible with the reorganization of the work in 1938. A subsequent report in preparation will show the relative distribution of the two species *S. elegans* and *S. setosa* within the area during 1938 and part of 1939. In the present account only the generic name Sagitta can be used.

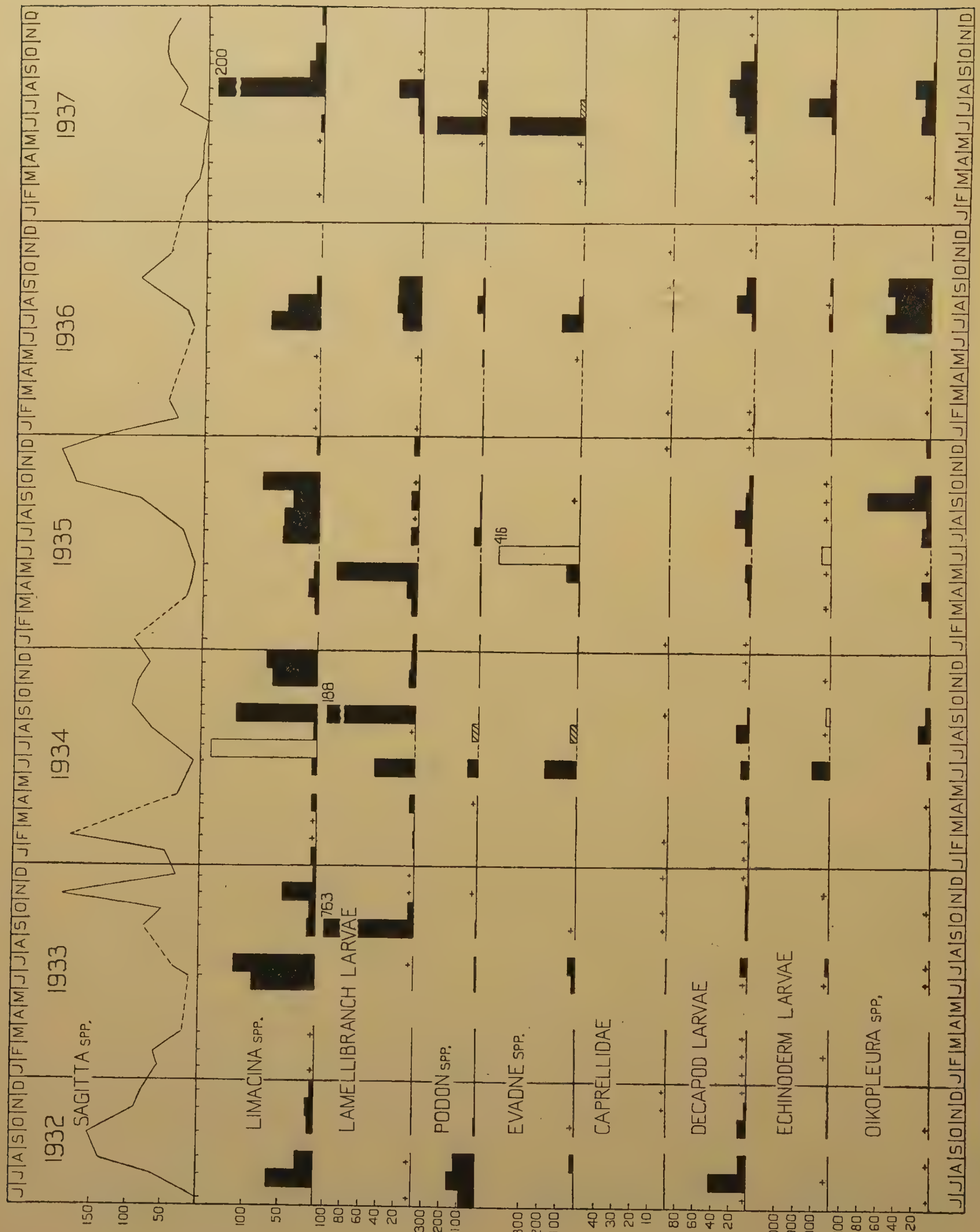
All the distribution data are shown in Plates CXXVI–CXXXI, the first of which explains the symbols in use, and the main seasonal changes from year to year for each line C, B and R are summarized in Text-figs. 1–3. The latter clearly show that Sagitta is taken in greatest numbers on the C line, in lesser numbers (except 1932) on the B line, and in only small numbers on the R line. The stock declines to a very low level on all lines in May and June. In July and August it increases again ; this first being noted on the C line, then on B. On the C line the numbers were high from 1932 to ’35, and much lower in ’36 and ’37 ; on the B line 1932 showed the highest numbers, and ’34 and ’35 were poor years. Particularly noteworthy are the high numbers found along the whole of the C line in February, 1934 (Plate CXXVIII). Meanwhile Sagitta was almost uniformly scarce on the R line, but in August and September there were small increases here also, usually over the eastern half of the line, but sometimes, as in 1934, in the west as well. In August, 1937 (Plate CXXXI), this is also shown on the southern end of the new E line, the whole patch apparently shifting to the north-east in September. The general changes in distribution east and west may be studied on the plates; sometimes the larger numbers are to the west, sometimes to the east and centre, although it is noteworthy that on the B line the numbers usually decrease towards the east.

From the data of the present survey it has been impossible to say to what extent the increase in each late summer is due to an "invasion" of fresh Sagitta into the area or to reproduction *in situ*. It is evident that young forms greatly increased about August; this may be compared with the results of Russell (1933), and in particular with his finding that Sagitta is more abundant in the surface waters in the late summer months. There are, however, some signs of incursion from the north (see also the 1938–39 report to be published shortly), and it is likely that both factors play a part.

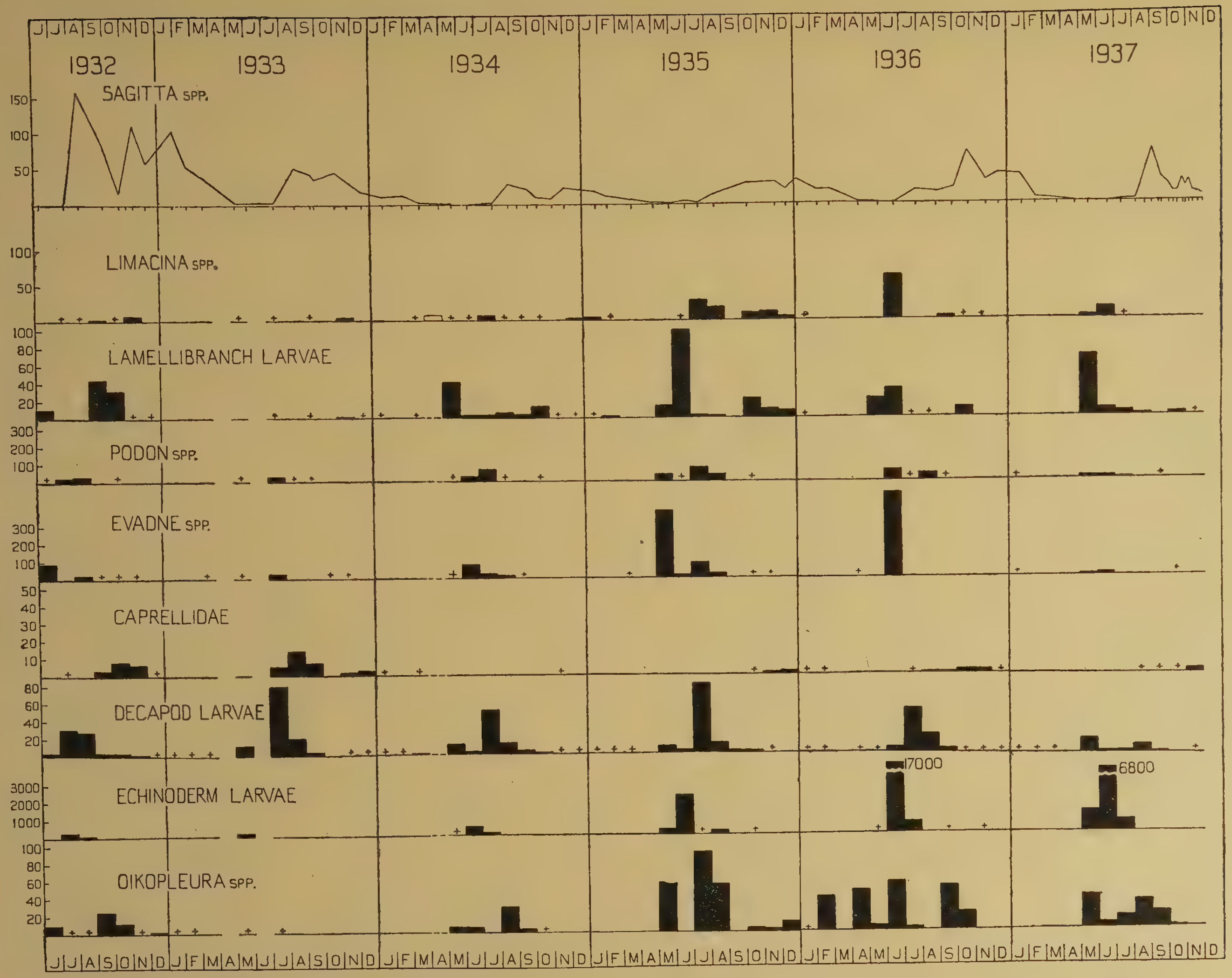
Limacina (Plates CXXXII–CXXXVII).

Although complete identification was not possible, the great majority, if not all, were *Limacina retroversa* Flemming. This species has its main distribution in the north-western North Sea, so it is not surprising that the denser patches were recorded on the northern line C. It was generally found in the largest numbers during the summer, appearing over or around the south-west or north-east ends of the Dogger Bank; the former patches were the stronger in 1932 and '37, the latter in 1934 and '36. After September it was never recorded in quantity except in November, 1934, when a relatively dense patch was observed over the Dogger Bank. On the B line it was only twice taken in numbers exceeding 9 per mile per block, *i.e.* in June, '36 and '37, although in the later half of 1935 it was found regularly along the whole route. It was only recorded on the R line in August, September and November, 1934, April and July to November, 1935, February, 1936, and June and July, 1937, but always fewer than 9 per mile per block.

The relative numbers on the different routes in different years are summarized in Text-figs. 1–3. It should be noted that the maximum figures shown for the C line in August, 1937, are actually less than those for the *first* September record in 1934 (see Plate CXXXIV). Limacina was most extensively found in 1935, perhaps indicating a widespread northern influence, but until more evidence is forthcoming regarding the fluctuations in numbers from year to year, and as to whether local breeding takes place or not, it will be difficult to assess its significance as an indicator of northern influence.



TEXT-FIG. 1.—Graph and histograms showing the average number of the commoner zooplankton forms (other than Copepoda) per ten-mile block on the Copenhagen line for each month from June, 1932, to December, 1937. The dates of the records are denoted by small vertical strokes below the base line of the Sagitta graph; elsewhere the absence of a record in any month is shown by a gap in the base line. Records of less than half of the normal length have been discarded and denoted by broken base lines in the histograms (see text, however, for explanation of open histograms). The shaded histograms denote Cladocera spp. indet.



TEXT-FIG. 2.—Graph and histograms showing the average number of the commoner zooplankton forms (other than Copepoda) per ten-mile block on the Bremen line for each month from June, 1932, to December, 1937. For explanation of arrangement, see legend of Fig. 1.

Clione (Plates CXXXV and CXXXVI).

Owing to the forms taken being small and much compressed by the recorder it has not been possible to identify this pteropod with certainty, but it is probably *C. limacina* Phipps. Its occurrence was very limited, appearing only in January, 1935, and in January and February, 1936, on the C line. The significance of these observations is better discussed in the later report, together with the more extensive records over the whole North Sea in 1938 and '39.

Lamellibranch Larvae (Plates CXLV and CXLVI).

The plates show that the most important part of the area for larval production is where the C line crosses the Dogger Bank. This could be expected ; it is well known from the work of Davis (1923, 1925) how rich the Dogger Bank is in Lamellibranchs. He showed that *Spisula subtruncata* (Da Costa) was the predominant species, with *Mactra stultorum* Linnaeus second, but much less abundant. The production on the B line is generally smaller, and on the R line very small indeed.

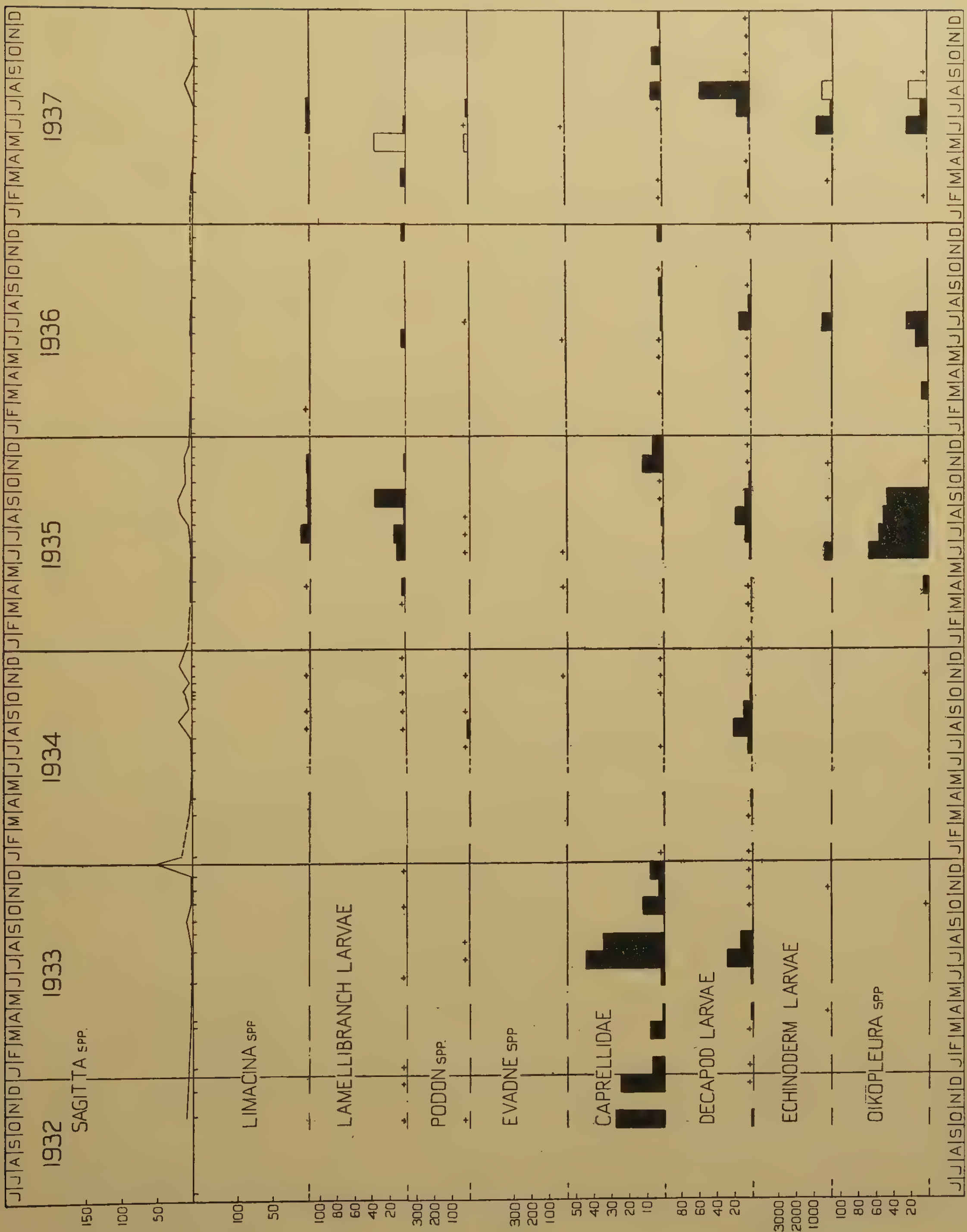
There is some evidence of two main productive periods in the year—May–June and September ; but a comparison of the different years as seen in Text-figs. 1–3 will show how very irregular are the productions as recorded in our survey. The results for the C and B lines are brought together in Table I, where a capital letter **C** or **B** indicates when the average number exceeds 20 per block for the whole of one or other line ; " –c " or " –b " indicates that no C or B record was obtained.

Table I.

	May.	June.	July.	August.	September.	October.
1932	–c, –b	. .	. .	. .	–c, **B**	**B**
1933	–c	–b	. .	–c	**C**	. .
1934	–c, **B**	**C**	–c	. .	**C**	–c
1935	**C**	–c, **B**	. .	. .	. .	**B**
1936	**B**	–c, **B**	**C**	**C**	**C**	–c
1937	**B**	. .	. .	**C**	. .	. .
	4	3	1	2	4	2

At times such patches of larvae may have been missed in the space between the lines ; more likely still, however, is it that some outbursts of larvae have been missed *in time* between one monthly record and the next. Davis (1925), writing of *Spisula subtruncata* (p. 24), says the length of the pelagic life of the larva is quite unknown, but suggests (p. 23) that a mean date of spawning may be "followed by a mean date of spat fall not many weeks or even days later."

Actually there is evidence in our survey that a period of high production may extend over at least a fortnight. The repeated C line in September, 1934 (Plate CXLV), gave a pattern of distribution on the 29th remarkably similar to that obtained



TEXT-FIG. 3.—Graph and histograms showing the average number of the commoner zooplankton forms (other than Copepoda) per ten-mile block on the Rotterdam line for each month from June, 1932, to December, 1937. For explanation of arrangement, see legend of Fig. 1.

on the 15th. It is clear that the recorder must be run more often if it is required to give a measure of the production of larval forms which have a planktonic life of less than a month. The value of these preliminary records lies, not in the actual information they provide, which is clearly inadequate, but in demonstrating how it might be possible in a general programme of fishery research to have a measure of the larval Lamellibranch production from year to year. The great importance of lamellibranchs as the food of plaice and other bottom-living fish is well recognized, and recorders on the C and new L line (Leith to Hamburg, begun in 1938), which cross the Dogger Bank in different directions, could be run at more frequent intervals, just as the B line has been run at weekly intervals for phytoplankton in the autumn. Davis indicates that the spawning season for *Spisula subtruncata* may extend from the beginning of June to the end of September.

Cladocera: Evadne and Podon (Plates CXLVII and CXLVIII).

The data for the two genera Evadne and Podon are charted separately except for three occasions (August, '34, and May and July, '37), when special conditions rendered identification uncertain. These doubtful cases are indicated by large stars on the Evadne charts, and the actual values of these undetermined Cladocera are shown on the Podon charts as squares. In Text-fig. 1 they are shown as cross-hatched histograms with those for both Podon and Evadne.

Evadne.—It is clear from both charts and histograms that Evadne was taken in highest numbers on the B and C routes, while it never reached significant proportions on the R route. It is an organism characterized by a relatively rapid appearance and disappearance. The high concentrations usually occur in May or June, or more rarely in July (*e.g.* 1936 C line). Numbers were comparatively low on both the C and B lines from 1932 to '34, but showing a gradual increase on the former. High numbers occur on both C and B in June, 1935; the C record is a short one, rather less than half the normal average, so the average figure cannot be compared with the averages for full records, but if the total value is averaged as if it constituted a complete record, a figure of 416 per block is obtained (shown as an open histogram in Text-fig. 1), which shows a great increase over 1934, and is nearly equal to the high figure for June, 1937, which is an average for a full record. In June, 1936, there was a very high concentration on the B line; unfortunately there was no C record in this month. In 1937 the production on B was very low, whereas that on C in June was high.

Podon.—As with Evadne, the more important concentrations were taken on the C and B lines, but never reached such high numbers. There was no outstanding concentration on B, and only in 1932 and '37 (see Text-fig. 1) were moderately high numbers taken on C.

A comparison of the relative numbers of the two genera (Text-figs. 1, 2 and 3) gives a general correspondence for route B, but Evadne increased more in proportion to Podon in 1935 and '36. On route C Podon was abundant in 1932 when

Evadne was at a minimum, while conversely Evadne appeared in high numbers in 1935, when Podon was very scarce. As with the Lamellibranch larvae, the monthly records probably do not give a sufficiently detailed picture of the variations in the populations, since both genera show a pronounced swarming habit and occur over a relatively short period. It is clear, however, that the conditions governing the relative numbers of the two genera vary very considerably over the different areas.

Caprellid Amphipoda (Plates CXLI and CXLII).

Reference to the charts will show that the main concentrations were found over the eastern part of the area, particularly off the Dutch coast on the eastern ends of the B and R routes. The group, however, became widespread over the B route in the latter months of 1933, '36 and '37. Throughout there was a general tendency for them to appear on the C route later in the year than on the more southerly routes.

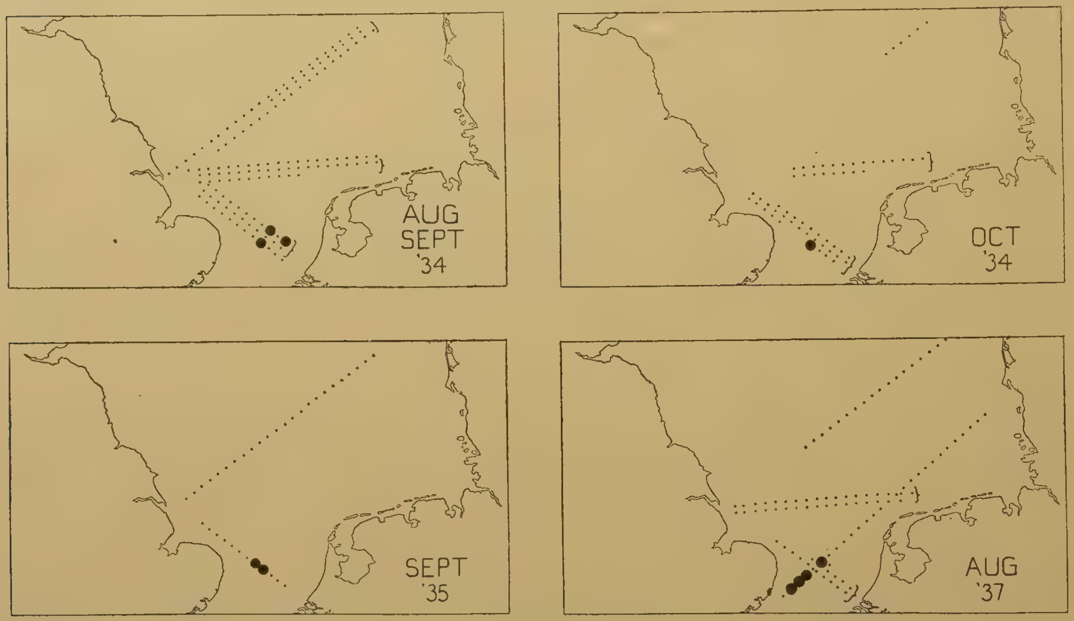
Text-figs. 1–3 show clearly a gradual reduction in numbers in a northerly direction, the densest populations being on the southerly R route and the most sparse on C. It will be seen that by far the highest numbers were taken on the B and R routes in 1932 and '33, while in marked contrast to this the averages were minimal in 1934 and quite low from 1935 to '37. The numbers on the C route were never sufficiently high to be plotted on the scale adopted for the histograms.

Regarding the tendency for the Caprellids to occur later in the year on the C route than on the others, there is some evidence to suggest a regular sequence in space and time for the appearance of the group. In the latter halves of 1933, '35, '36 and '37 they first appeared on the R route, then on the B route and finally on the C route, the region of the R route forming perhaps a nearby permanent reserve. As the Caprellids are generally considered to be tychopelagic forms, this northerly sequence may give important information regarding the changes in vertical water movements over the area as well as the possibility of "drift."

Decapod Larvae (Plates CXXXVIII–CXL).

The Decapod larvae were present over the southern North Sea during each month of the whole period. Generally speaking the main production begins in May, reaching a maximum in July or August, and starts to decline in September. It will be seen that production tends to be concentrated in well-defined areas. Thus the numbers are generally higher over the eastern part of the B line, the western part of the C line and, rather in contrast to other forms, the Humber end of the R line. The E line showed a large production in the Heligoland Bight region in July, 1937, suggesting that the higher numbers which are found on the eastern half of B may be part of an intense general production which is associated with the Heligoland Bight and neighbouring areas. Before and after this summer production, *i.e.* over the periods January to April and October to December, a rather sparse population of larvae is to be found.

If the annual variations shown in Text-figs. 1–3 are examined it will be seen that, while there is little evidence for a general trend of larval production over the whole area, certain trends are apparent on the different routes. On C and B there was a moderate production in July and August, 1932, while in July, 1933, maximum numbers were found. Savage (1937) found the herring to be eating Decapod larvae more in 1933 than in 1932 or '34. After a drop in numbers in 1934 the average for July, 1935, shows practically the same value as that obtained for 1933, while 1936 and '37 show a progressively decreasing production. The population on R was very small in 1932, but fairly numerous in 1933, thereafter gradually decreasing up to the end of 1936. In 1937, however, maximum numbers were taken in August. The trend for the C route is exactly opposite to that on the R route from 1932 to '36. Maximum quantities were taken in July, 1932, falling to a minimum in 1933, but from 1934 to '37 there occurred a progressive increase, the largest number for each of these years falling in August.



TEXT-FIG. 4.—Charts showing the occurrence of Alima larvae of Squilla spp. during the period 1932–37.

Stomatopod Larvae.

In the late summer or autumn, of three years out of six (1934, '35 and '37) the Alima larvae of Squilla (species undetermined) have been taken on the recorder lines always in the same region where the Channel opens into the Southern Bight.

The positions and months of the occurrences are shown in Text-fig. 4, where it will be seen that they were most persistently found in 1934, from August to October. Adult specimens of Squilla have very rarely been recorded for the North Sea, but two species, *S. mantis* (L.) and *S. desmaresti* Risso, are from time to time taken on the French and English coasts of the Channel, and Squilla larvae have been recorded as far north as the Dogger Bank. It seems likely that these larvae may be used as important indicators of water movements in this area when more is known of the spawning of the adults.

Echinoderm Larvae (Plate CXLIX).

The main centres of production were off the Dutch-German coast and the north-east border of the Dogger Bank (probably extending to the Danish coast as shown by the E and extended C lines in July, '37), whilst smaller numbers occurred over the western half of B. They appeared in notable abundance off the Dutch coast in July, 1935, '36 and '37, and over the Dogger Bank in June, July and September, '34, and July, '37.

Text-figs. 1–3 show that production on the B line was by far the most important, although numbers were very low until 1935, increasing further to very high figures in '36 and '37. Line R followed line B closely, but with much smaller numbers, there being practically no records until June, '35, to be followed by slight increases in '36 and '37. On the C route broods were poor except for the developments over the Dogger region in '34 and '37.

Oikopleura (Plates CXLIII–CXLIV).

It was not possible to identify the species concerned.[1] The charts show the whole distribution except for traces on the B line in November and December, 1932, January and February, '33, and October, '37, and larger quantities on the C and R lines in September, '35, the chart for which was omitted in error from Plate CXLIV, but is shown as a figure with the explanation of the Plates on p. 273.

The histograms of monthly averages for the three routes show a markedly similar trend over the period. Oikopleura was particularly sparse from 1932 to '34, only reaching values higher than 20 on the B route in September and August of 1932 and '34 respectively. Maximum numbers, however, occurred in 1935 in June on the R route, July on B, and September on C. In 1936, although there was a decrease in maximal numbers relative to 1935, the averages on the B and C routes were still comparatively high. On the former route in 1936 they were taken in irregular abundance on four occasions over the period February to September. By 1937 the averages on the B and C routes had fallen appreciably, while the R route showed values much the same as in 1936.

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[1] Oikopleura usually suffered much damage on the silk and was often broken up. This condition has been somewhat improved by the device introduced at the end of 1937 (Hardy, 1939, p. 26), and it is hoped that specific identification may be made in later surveys.

This form was clearly most abundant over the B line. The extraordinary scarcity in 1933 recalls the fact that Savage (1937) found it to be scarcer in the herring food off Shields in that year.

Other Zooplankton Forms.

Apart from the Mysidacea and Euphausiacea, which have been omitted for the reasons already given (p. 258), a number of other forms were taken in small numbers and about which no useful distributional information can be given from the present survey; they include radiolarians, various medusae (badly damaged by the recorder), Hyperiid Amphipoda and Amphioxus larvae (taken over the Dogger Bank). These records may be used in later reports, when further data may add to their significance.

The General Community.

To conclude the account it may be well to outline the general ecological picture that can be gathered from the survey, particularly regarding those characters of distribution which the plankton recorder is specially designed to show by its continuity of action.

Apart from the copepods Paracalanus, Pseudocalanus, Temora and Acartia (see Rae and Fraser, 1941), Sagitta is the only zooplankton form which is nearly always present, and with them forms the basic predominant core of the animal community. Sagitta each year falls to a low ebb in May and June, but it is seldom completely absent from a record. While sparser in the south, it is widely spread throughout the region. Rarely does it form dense confined concentrations; a study of the charts will show that more often than not it is very evenly spread along the line of observation. Both distribution charts and time graphs (Text-figs. 1–3) show on the whole that populations rise and fall gradually; where lines have been repeated in the same month the distribution and quantities shown on consecutive runs are usually very similar (September, '33; September and October, '34; January, August and November, '35; February, '36; October and November, '37), and the few exceptions are mostly in August at the time of rapid increase (November, '32; August, '34; August, '36; and August, '37).

Next in usual presence are the decapod larvae, but more spasmodic in time and, as already described, occurring densely in definite areas. These areas are usually fairly wide in extent, and production may be heavy and remarkably even for long distances, particularly in July; as examples see the 90-mile stretch of uniform values at the north end of the E line in July, '37, and the long stretches of fairly even production on the B line in August, '32 (80 miles), July, '33 (140 miles), July, '34 (90 miles), July, '35 (110 miles), and July, '36 (110 miles).

Limacina is a summer and autumn form rarely occurring in the southern part of the area. It may be present in small numbers over long stretches at a time, but the higher numbers are usually more confined to definite patches of 40 miles or less.

The Cladocera come and go with a short burst of production, usually showing very dense concentrations of limited area. For Evadne (Plate CXLVII) see June, '32, July, '33, April, May, June and July, '35, June and July, '36, and for Podon (Plate CXLVIII), June, July and August, '32, June and July, '34, April and July, '35, June and August, '36. Evadne was more widespread in June, '34, and both genera showed an unusually wide distribution in June, '37.

Oikopleura is never taken in large numbers by the recorder; Text-figs. 1–3 show that it was much less abundant in the first three years of the survey than in the last three.

The patchy nature of the outbursts of Lamellibranch larvae has already been commented on (p. 264), while the Echinoderm larvae sometimes occur in great numbers over considerable stretches of the lines, *e.g.* June, '35, June, '36, June and July, '37.

The Caprellids, bottom-living forms coming up into the plankton, are sometimes widely spread as in August and September, '33, September and October, '36, and August to November, '37, or sometimes more confined in area as in 1933, '34 and '35.

Looking at the sequence of years (Text-figs. 1–3), one is struck by the general poverty of the plankton in 1933; this applied not only to the forms considered here. Rae and Fraser (1941) write of the Copepoda: "Although the successful preceding autumn crops were reflected in the early months of 1933 for some species, this was, on the whole, the leanest year of the survey."

SUMMARY.

1. The report describes the main monthly changes in the distribution and abundance of the zooplankton, other than Copepoda and young fish (dealt with in separate reports), over the southern part of the North Sea from 1932 to 1937. The work is part of the survey carried out by continuous plankton recorders towed at a depth of 10 metres on regular steamship lines between England and the Continent.
2. The limitations to the sampling method are discussed, and it is shown to be unsuitable for recording Mysidacea and Euphausiacea on account of their marked diurnal variation due presumably to vertical migration; they are omitted from the report.
3. The changing distribution of Sagitta, Limacina, Clione, Lamellibranch larvae, Cladocera, Caprellid Amphipoda, Decapod larvae, Echinoderm larvae and Oikopleura are shown in a series of monthly charts while their seasonal fluctuations are compared in time-chart histograms.
4. The Alima larvae of Squilla are recorded on a few occasions in the regions where the Channel opens into the North Sea.
5. The distributional characteristics of the different forms, *i.e.* their tendencies to even or "patchy" production, are compared.

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EXPLANATION OF PLATES CXXVI TO CXLIX.

GENERAL EXPLANATION.

Charts showing the distribution of the more important zooplankton organisms other than Copepoda and young fish as found by the plankton recorder survey of the southern North Sea from June, 1932, to December, 1937. The numerals and/or symbols denote the varying numbers *either* per 10-mile block *or* per mile per 10-mile block as is indicated together with the scale of symbols on the first plate for each group of organisms. When more than one record has been obtained in any month they have usually been shown "in parallel" (the earlier one above) and bracketed together; if more than two were obtained the additional ones may be shown below the chart, as, for example, September to November on Plate CXXXI. The day of the month on which each record (or the greater part of the record) was taken is shown enclosed in a circle opposite the eastern extremity of the line.

PLATES CXXVI–CXXXI.

Charts showing the distribution of members of the genus Sagitta month by month from June, 1932, to December, 1937.

PLATES CXXXII–CXXXVII.

Charts showing the distribution of the genus Limacina (largely, if not entirely *Limacina retroversa*) month by month from June, 1932, to December, 1937.

Occurrences of the Pteropod *Clione limacina* are shown by a special symbol.

Plates CXXXVIII–CXL.

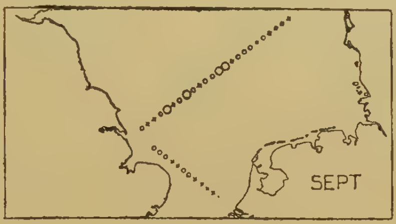
Charts showing the distribution of Decapod larvae month by month from June, 1932, to December, 1937.

Plates CXLI, CXLII.

Charts showing the distribution of the Caprellid Amphipoda for just those months in which they were recorded from June, 1932, to December, 1937.

Plates CXLIII, CXLIV.

Charts showing the distribution of Oikopleura in all those months in which they occur from June, 1932, to December, 1937, except for small traces referred to in the text (see page 269), and a chart for September, 1935, which was in error omitted from Plate CXLIV and is shown below.



Plates CXLV, CXLVI.

Charts showing the distribution of the Lamellibranch larvae for those months in which they occur between June, 1932, and December, 1937.

Plates CXLVII, CXLVIII.

Charts showing the distribution of the Cladocera (Evadne and Podon) in those months in which they occur in the period June, 1932, to December, 1937. On three occasions (August, 1934, and May and July, 1937) circumstances made the identification of the Cladocera doubtful. These records are shown by special symbols on the Podon charts on Plate CXLVIII, and the positions of these indetermined Cladocera are shown on the Evadne plate as large asterisks.

Plate CXLIX.

Charts showing the distribution of the Echinoderm larvae for those months in which they occurred during the period June, 1932, to December, 1937.

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SAGITTA SPP. 1932

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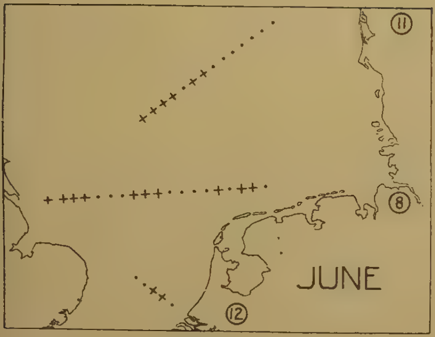

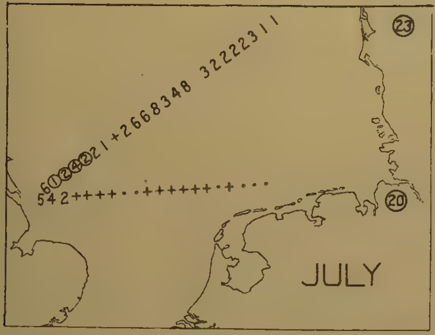
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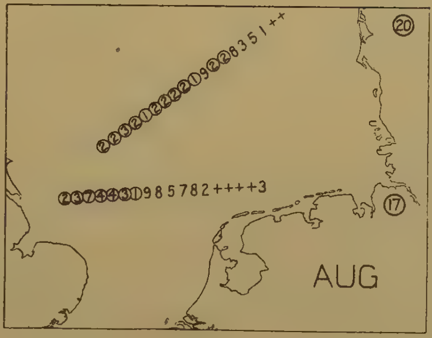
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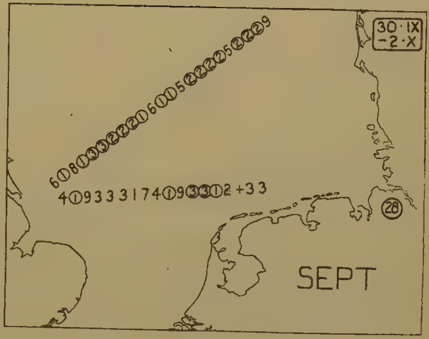
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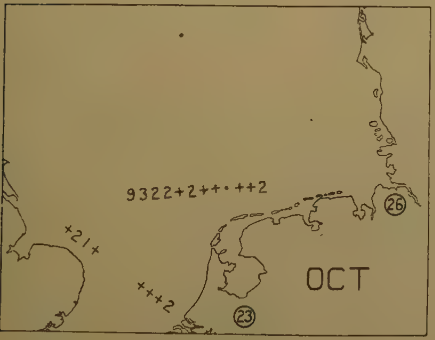
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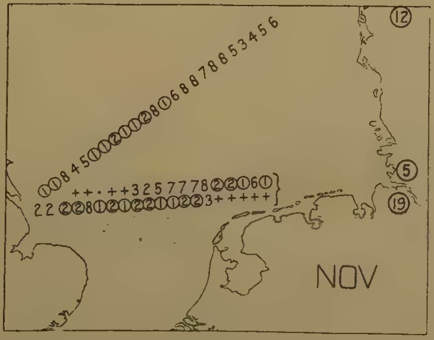
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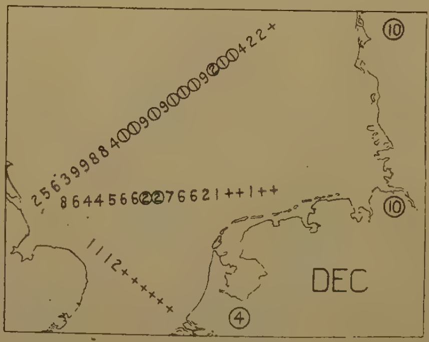
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PLATE CXXVII

SAGITTA SPP. 1933

SCALE ON PLATE CXXVI

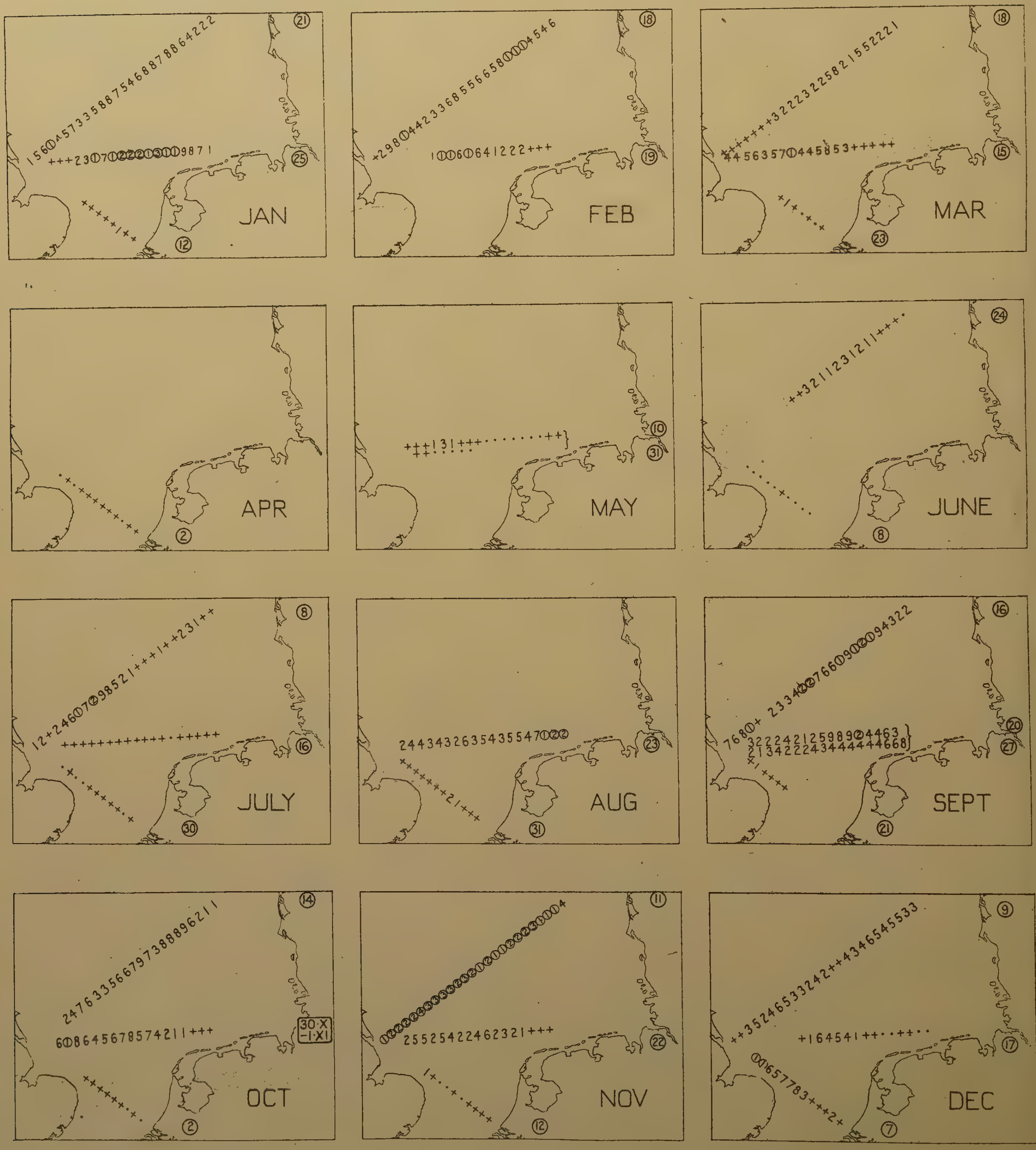
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PLATE CXXVIII

SAGITTA SPP. 1934

SCALE ON PLATE CXXVI

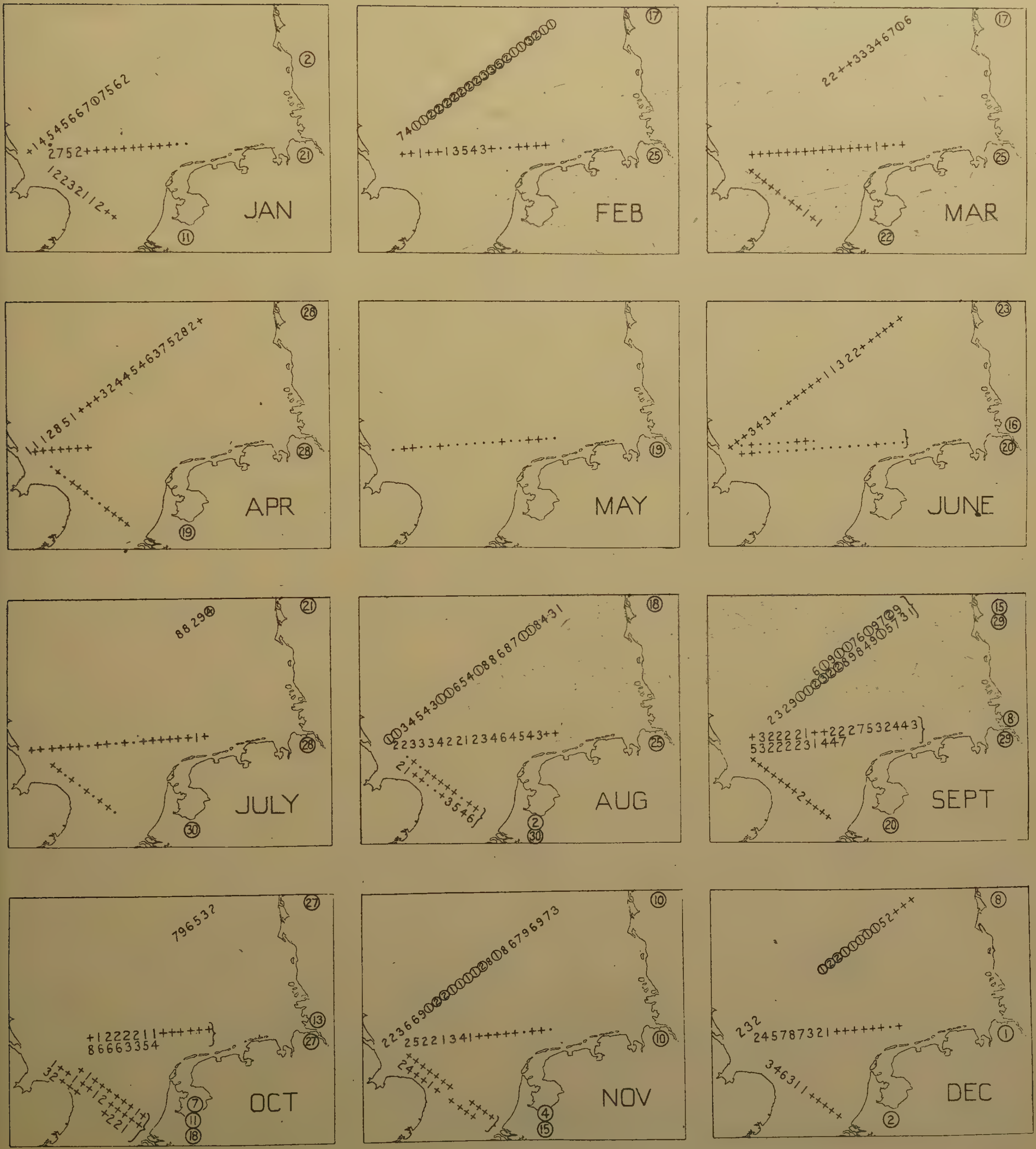
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PLATE CXXIX

SAGITTA SPP. 1935

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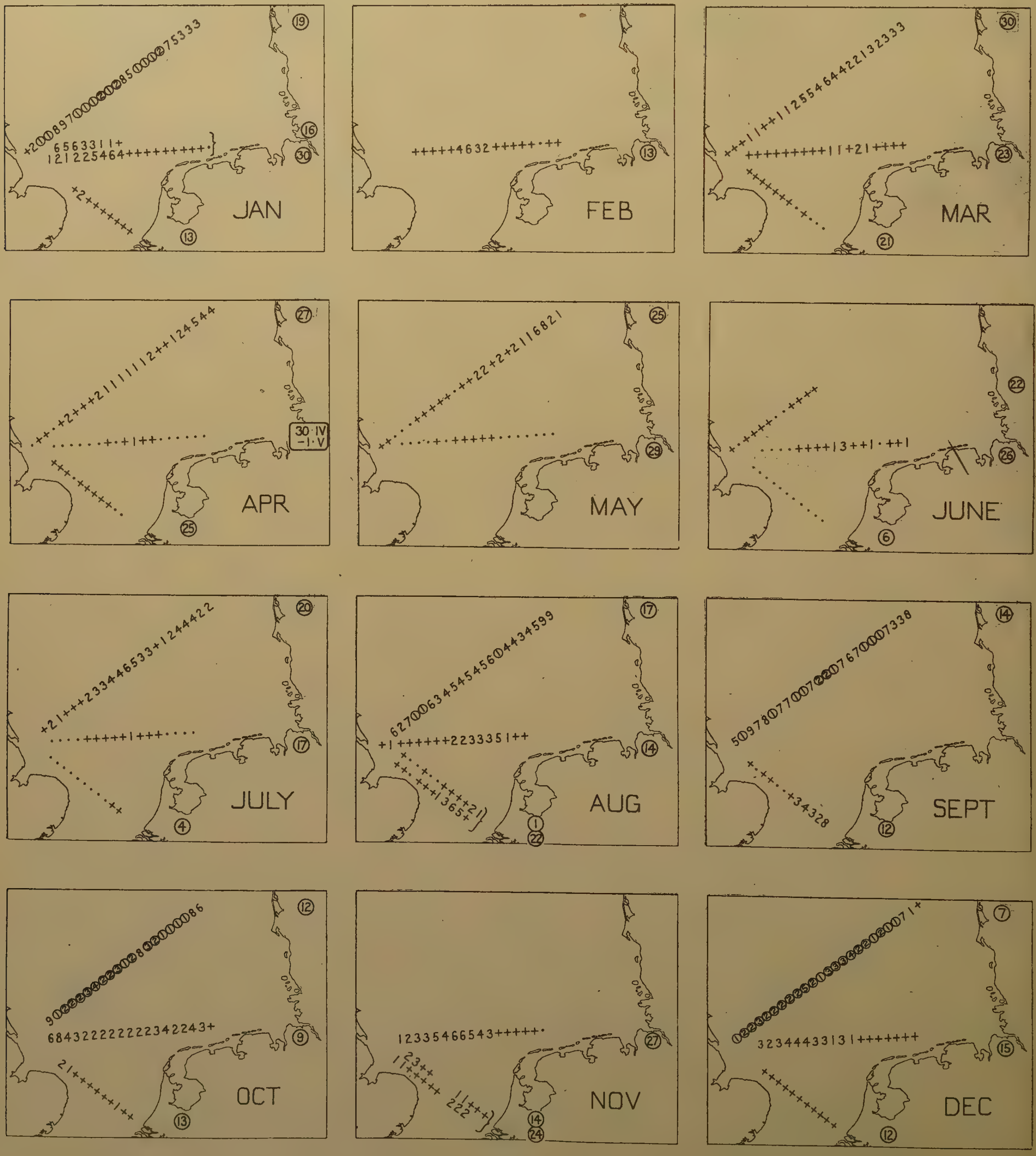
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PLATE CXXX

SAGITTA SPP. 1936

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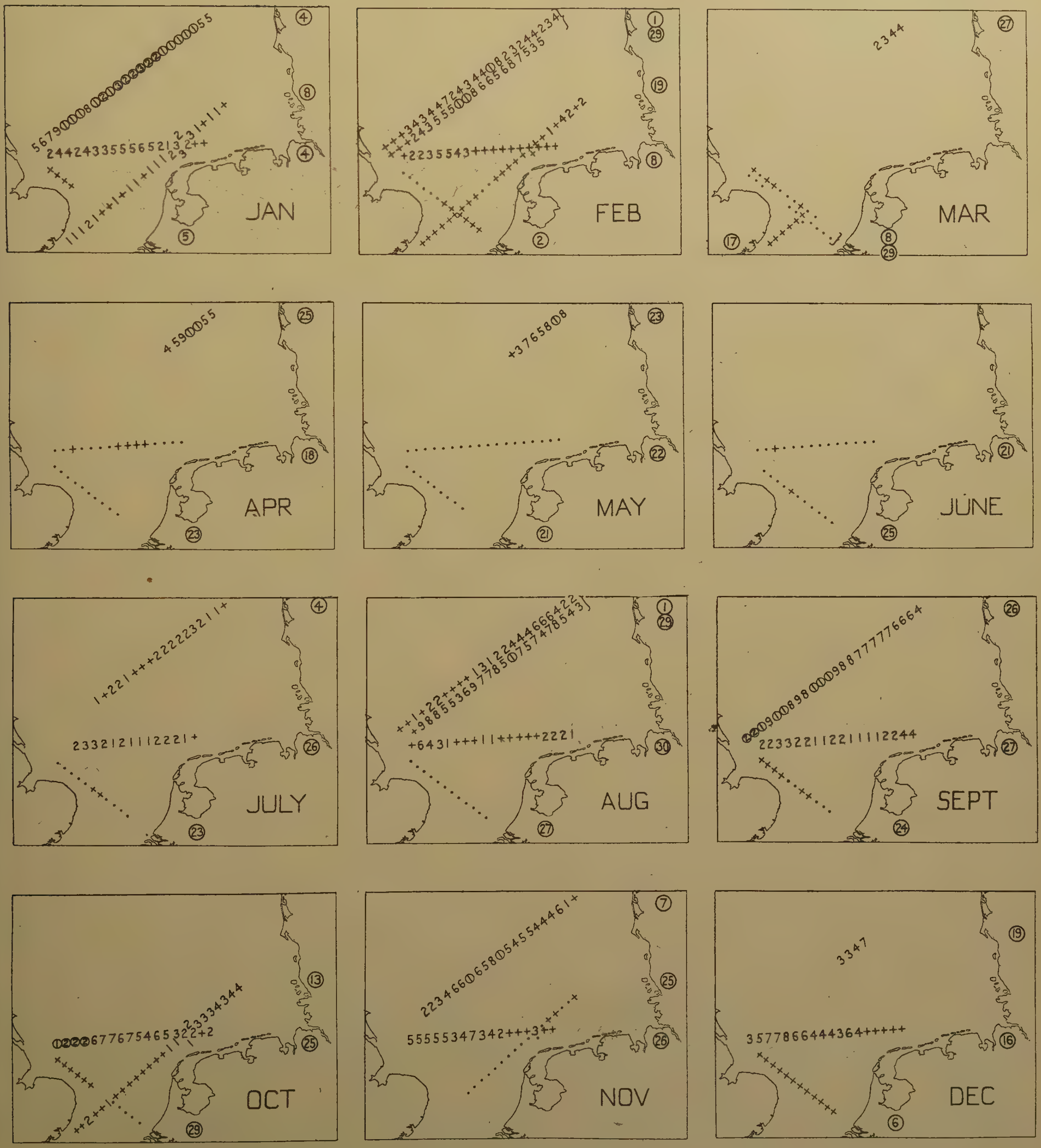
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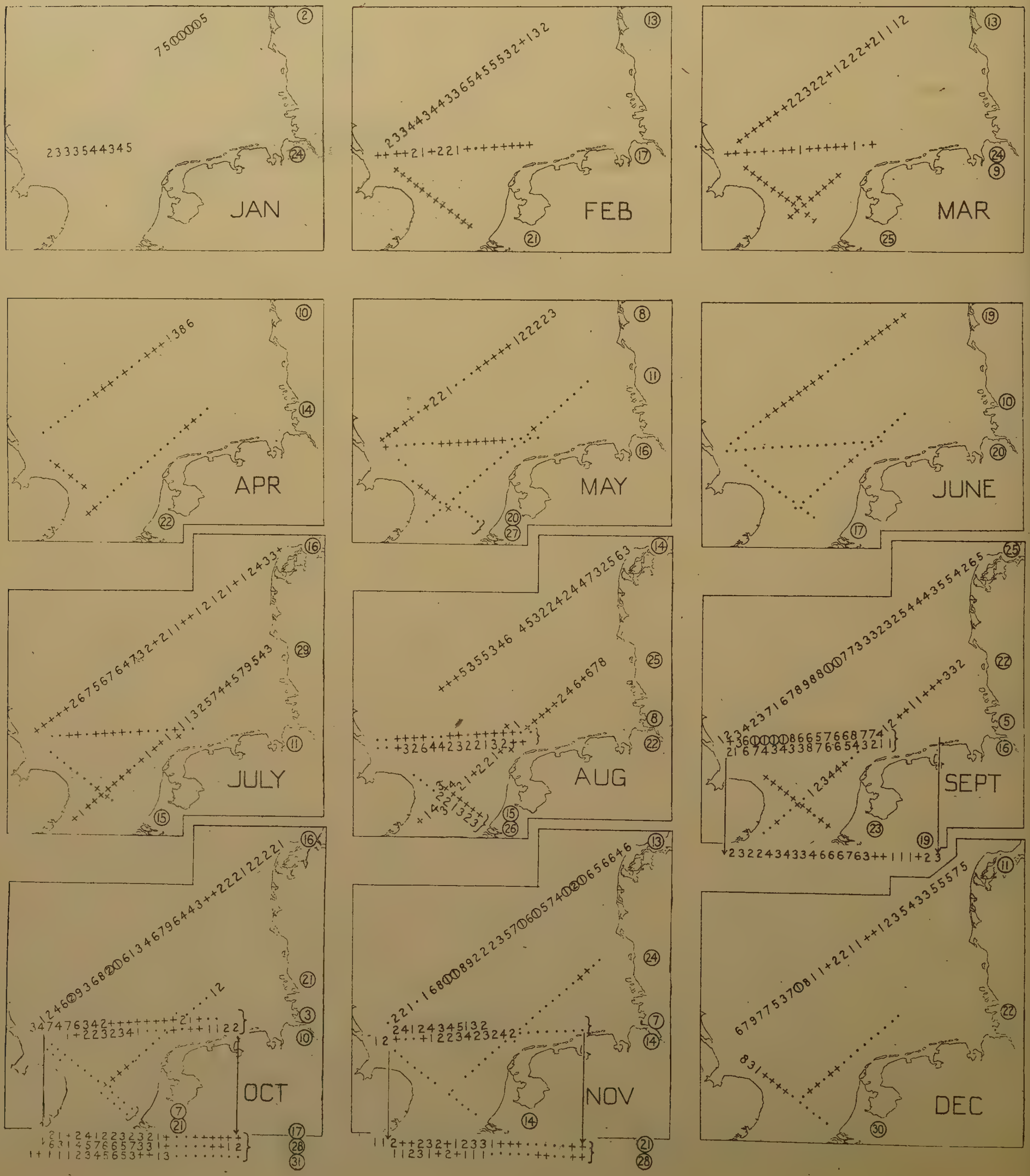
PLATE CXXXI

SAGITTA SPP. 1937

SCALE ON PLATE CXXVI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LIMACINA SPP. 1932

[ALSO *CLIONE LIMACINA*
IF RECORDED
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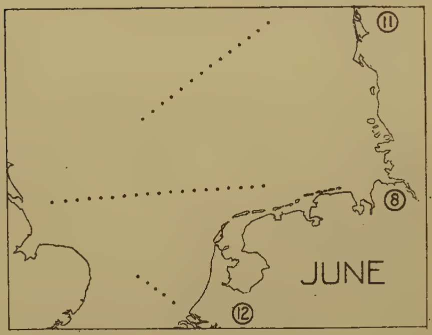
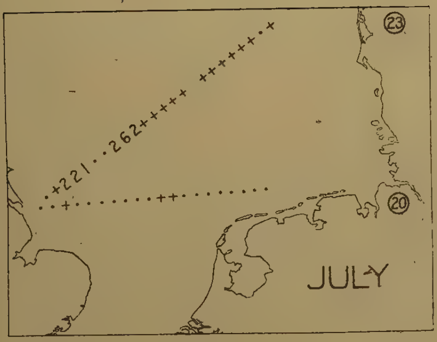
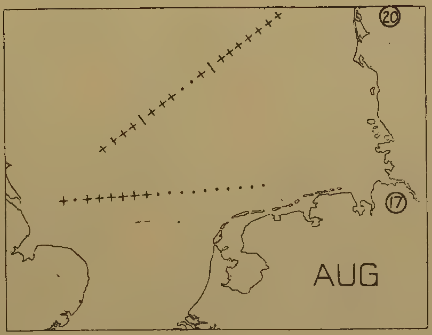
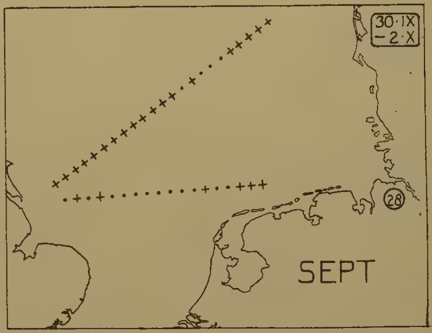
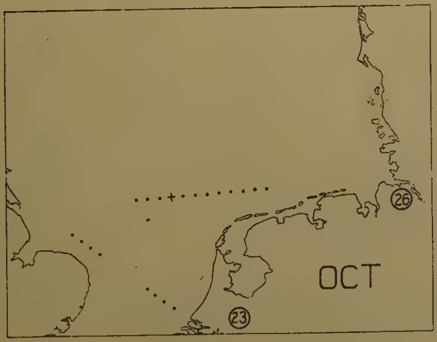
PER MILE PER BLOCK

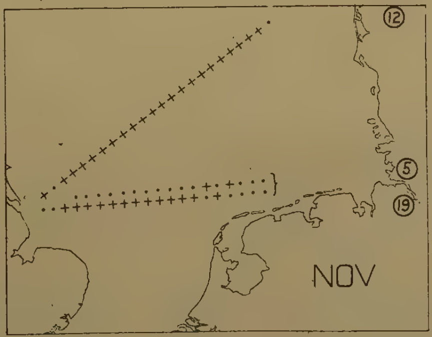



㉓
+221··262
⑳
JULY




30·IX
-2·X
㉘
SEPT





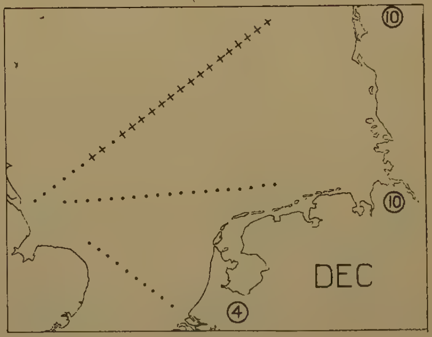


PLATE CXXXIII

LIMACINA SPP. 1933

SCALE ON PLATE CXXXII

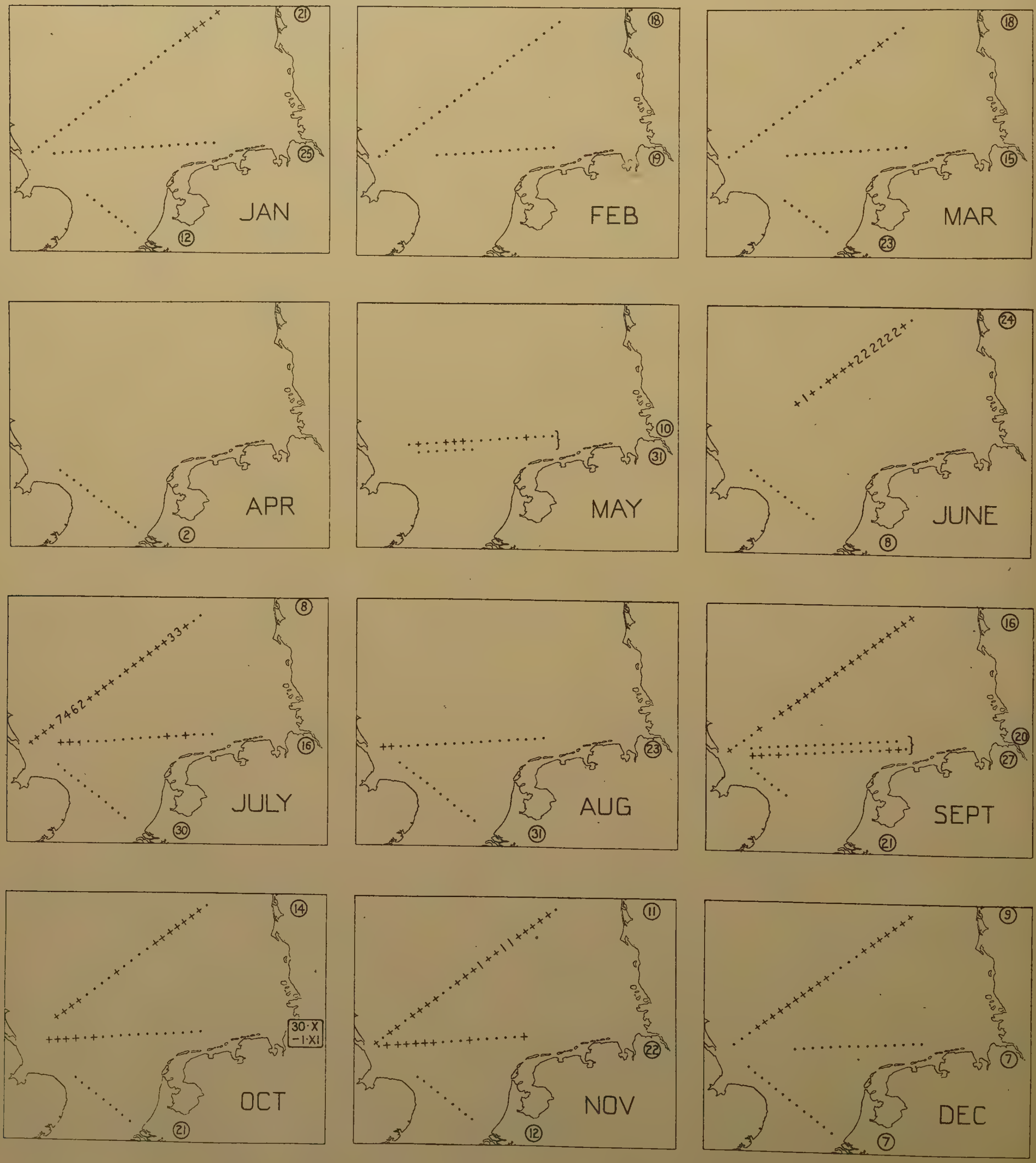

JAN
㉑
㉕
⑫
FEB
⑱
⑲
MAR
⑱
⑮
㉓
APR
②
MAY
⑩
㉛
JUNE
㉔
1
2222222
⑧
JULY
⑧
7462
33
⑯
㉚
AUG
㉓
㉛
SEPT
⑯
⑳
㉗
㉑
OCT
⑭
30·X
–1·XI
㉑
NOV
⑪
㉒
⑫
DEC
⑨
⑦
⑦

PLATE CXXXIV

LIMACINA SPP. 1934

SCALE ON PLATE CXXXII

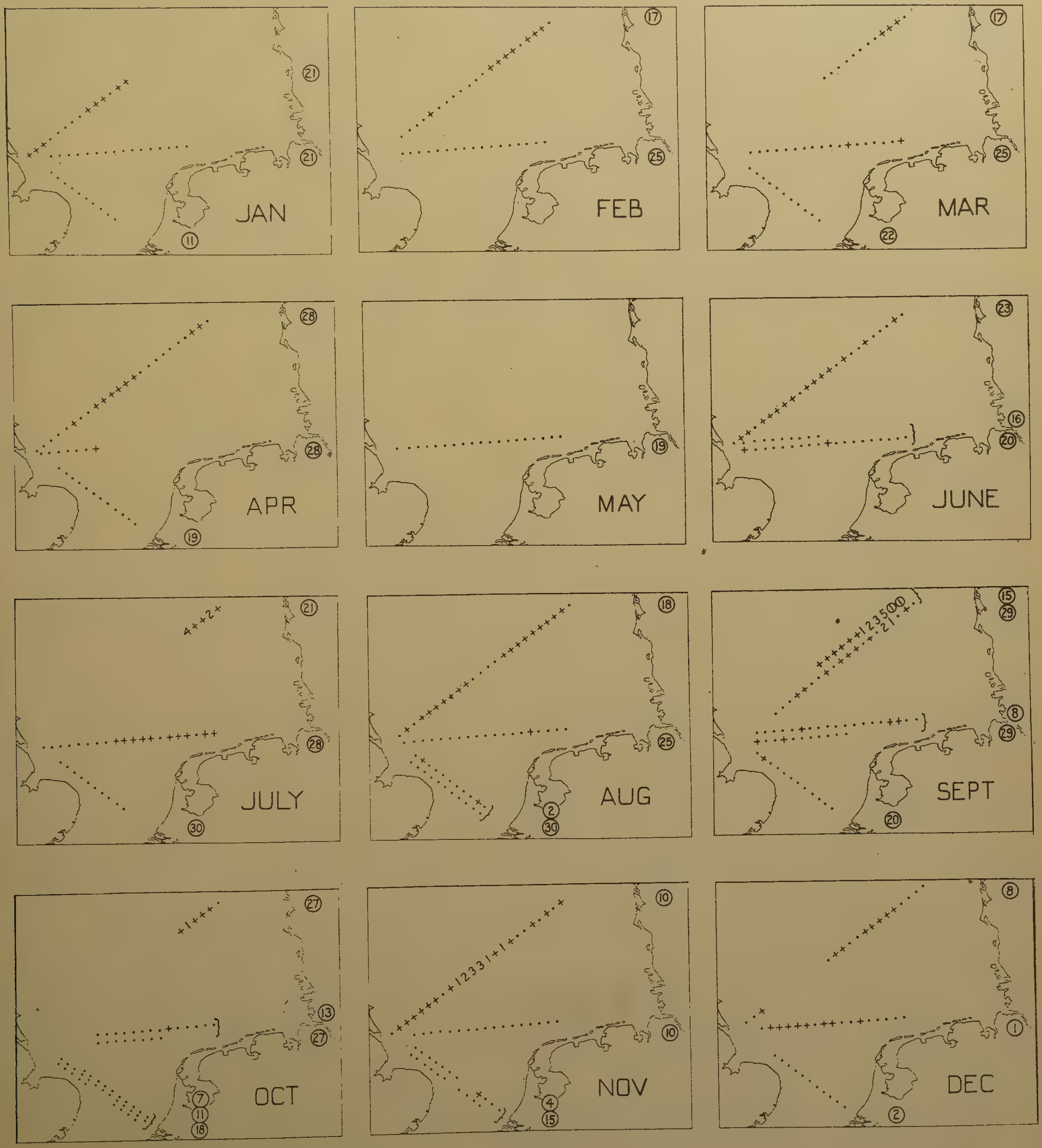

JAN
㉑
㉑
⑪
FEB
⑰
㉕
MAR
⑰
㉕
㉒
APR
㉘
㉘
⑲
MAY
⑲
JUNE
㉓
⑯
⑳
JULY
4++2+
㉑
㉘
㉚
AUG
⑱
㉕
②
㉚
SEPT
+1235⑩⑩
21
⑮
㉙
⑧
㉙
⑳
OCT
+1+++
㉗
⑬
㉗
⑦
⑪
⑱
NOV
+12331+1
⑩
⑩
④
⑮
DEC
⑧
①
②

PLATE CXXXV

LIMACINA SPP. 1935

ALSO *CLIONE LIMACINA*: ✝

SCALE ON PLATE CXXXII

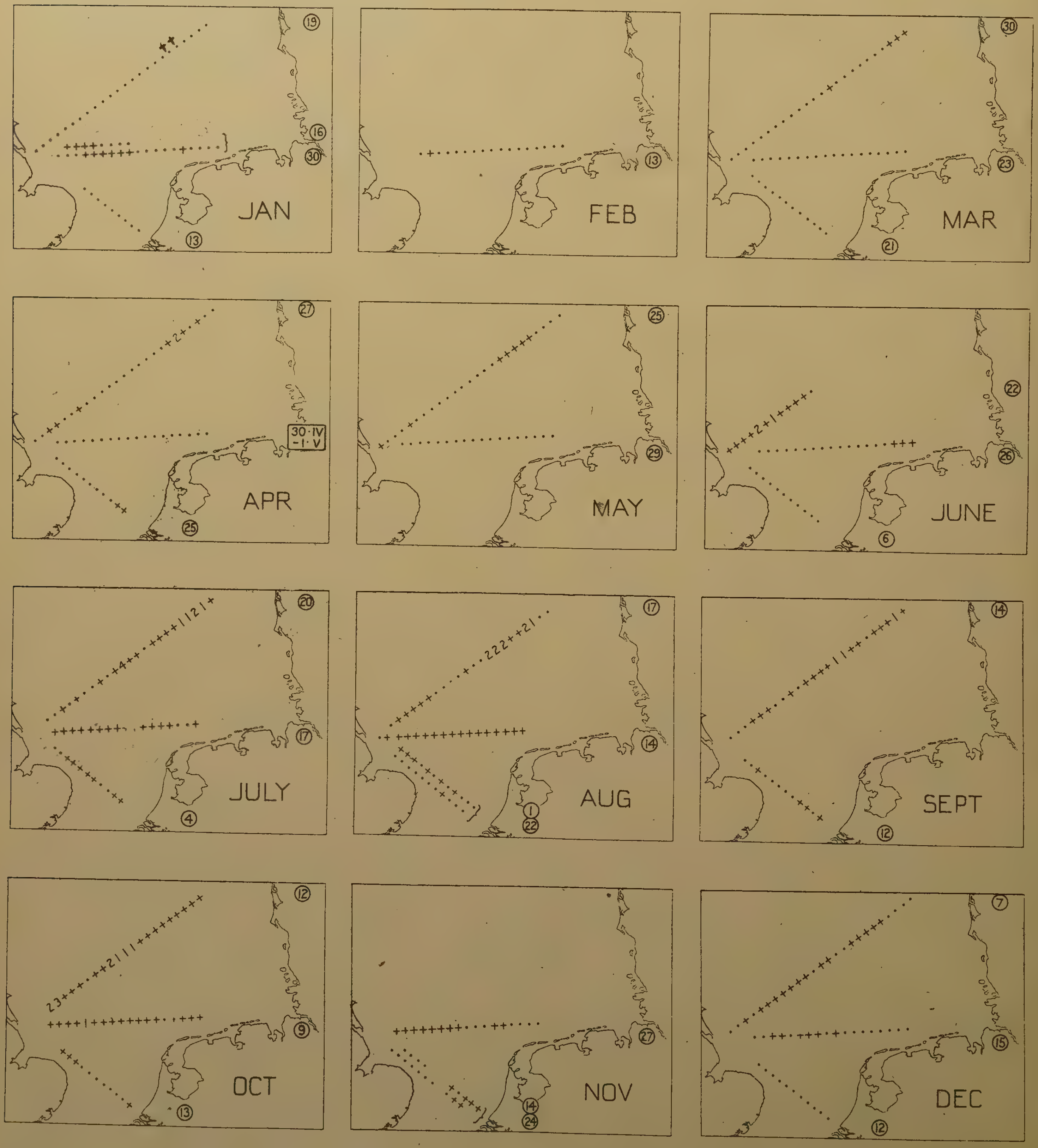

⑲
⑯
㉚
⑬
JAN
⑬
FEB
㉚
㉓
㉑
MAR
㉗
30·IV -1·V
㉕
APR
㉕
㉙
MAY
㉒
㉖
⑥
JUNE
⑳
⑰
④
JULY
⑰
⑭
①
㉒
AUG
⑭
⑫
SEPT
⑫
⑨
⑬
OCT
㉗
⑭
㉔
NOV
⑦
⑮
⑫
DEC

PLATE CXXXVI

LIMACINA SPP. 1936

ALSO *CLIONE LIMACINA* : †

SCALE ON PLATE CXXXII

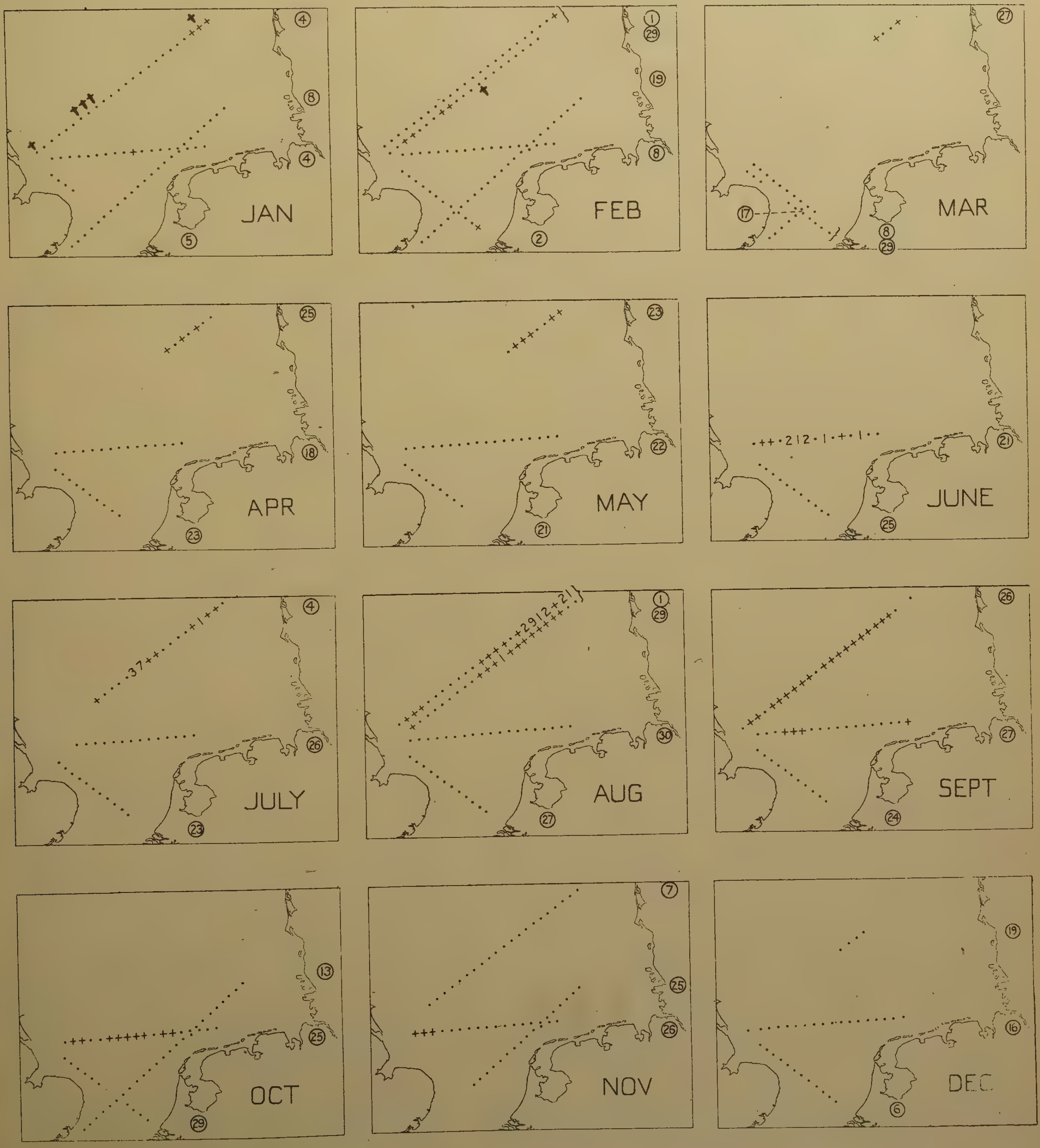
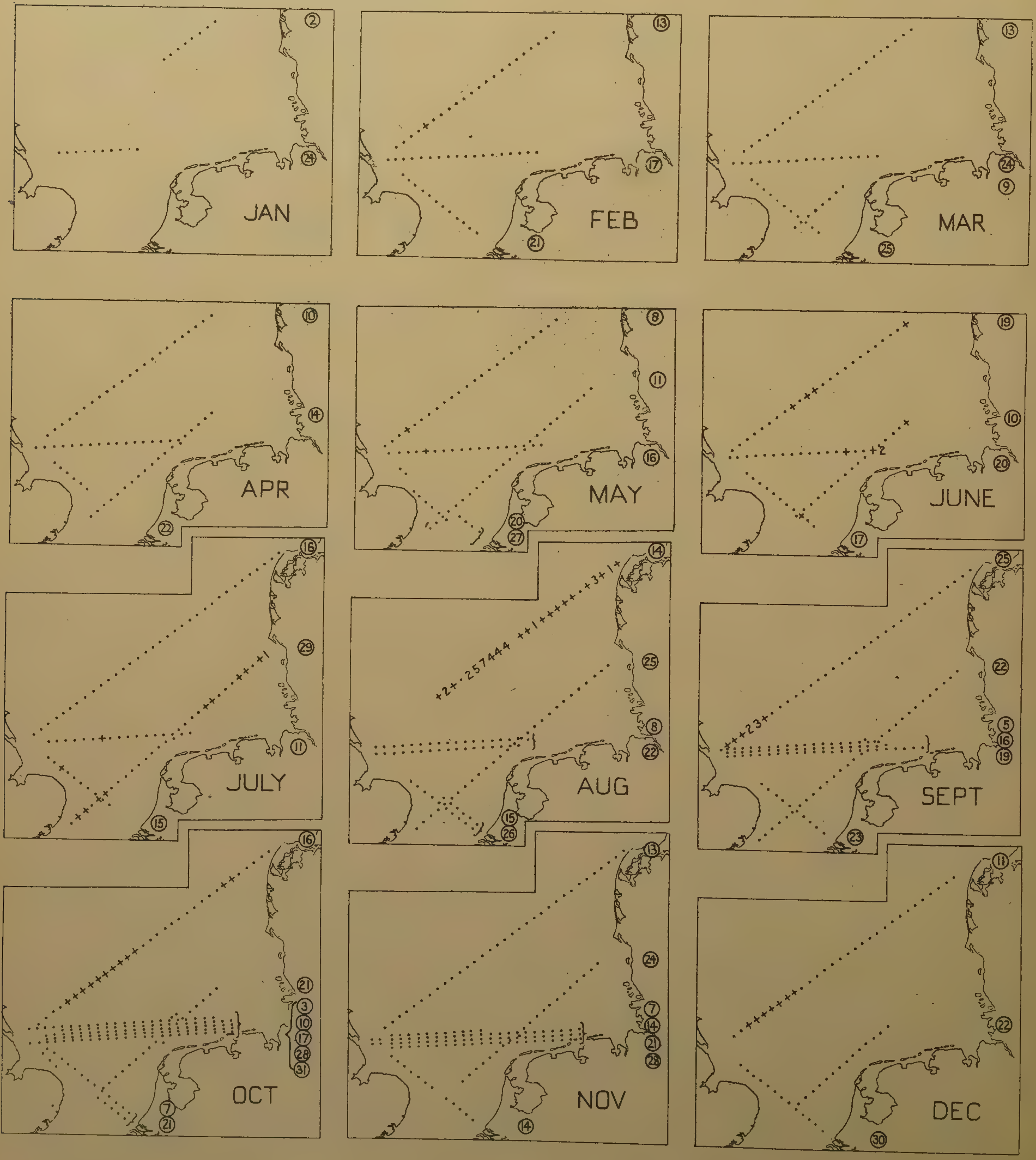

④
⑧
④
⑤
JAN
①
㉙
⑲
⑧
②
FEB
㉗
⑰
⑧
㉙
MAR
㉕
⑱
㉓
APR
㉓
㉒
㉑
MAY
2 1 2 1 1
㉑
㉕
JUNE
④
37
1
㉖
㉓
JULY
①
㉙
29 12 21
㉚
㉗
AUG
㉖
㉗
㉔
SEPT
⑬
㉕
㉙
OCT
⑦
㉕
㉖
NOV
⑲
⑯
⑥
DEC

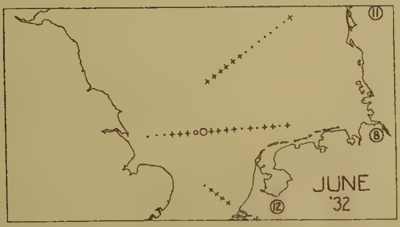
PLATE CXXXVII

LIMACINA SPP. 1937

SCALE ON PLATE CXXXII


②
㉔
JAN
⑬
⑰
㉑
FEB
⑬
㉔
⑨
㉕
MAR
⑩
⑭
㉒
APR
⑧
⑪
⑯
⑳
㉗
MAY
⑲
⑩
2
⑳
⑰
JUNE
⑯
1
㉙
⑪
⑮
JULY
⑭
+2+·257444 ++1+++++·+3+1+
㉕
⑧
㉒
⑮
㉖
AUG
㉕
㉒
+++23+
⑤
⑯
⑲
㉓
SEPT
⑯
㉑
③
⑩
⑰
㉘
㉛
⑦
㉑
OCT
⑬
㉔
⑦
⑭
㉑
㉘
⑭
NOV
⑪
㉒
㉚
DEC

DECAPOD LARVAE



SCALE

• - 0
+ - 1-10
∘ - 11-25
○ - 26-50
⊕ - 51-100
◒ - 101-250
● - 251-500

~~PER MILE~~
PER BLOCK

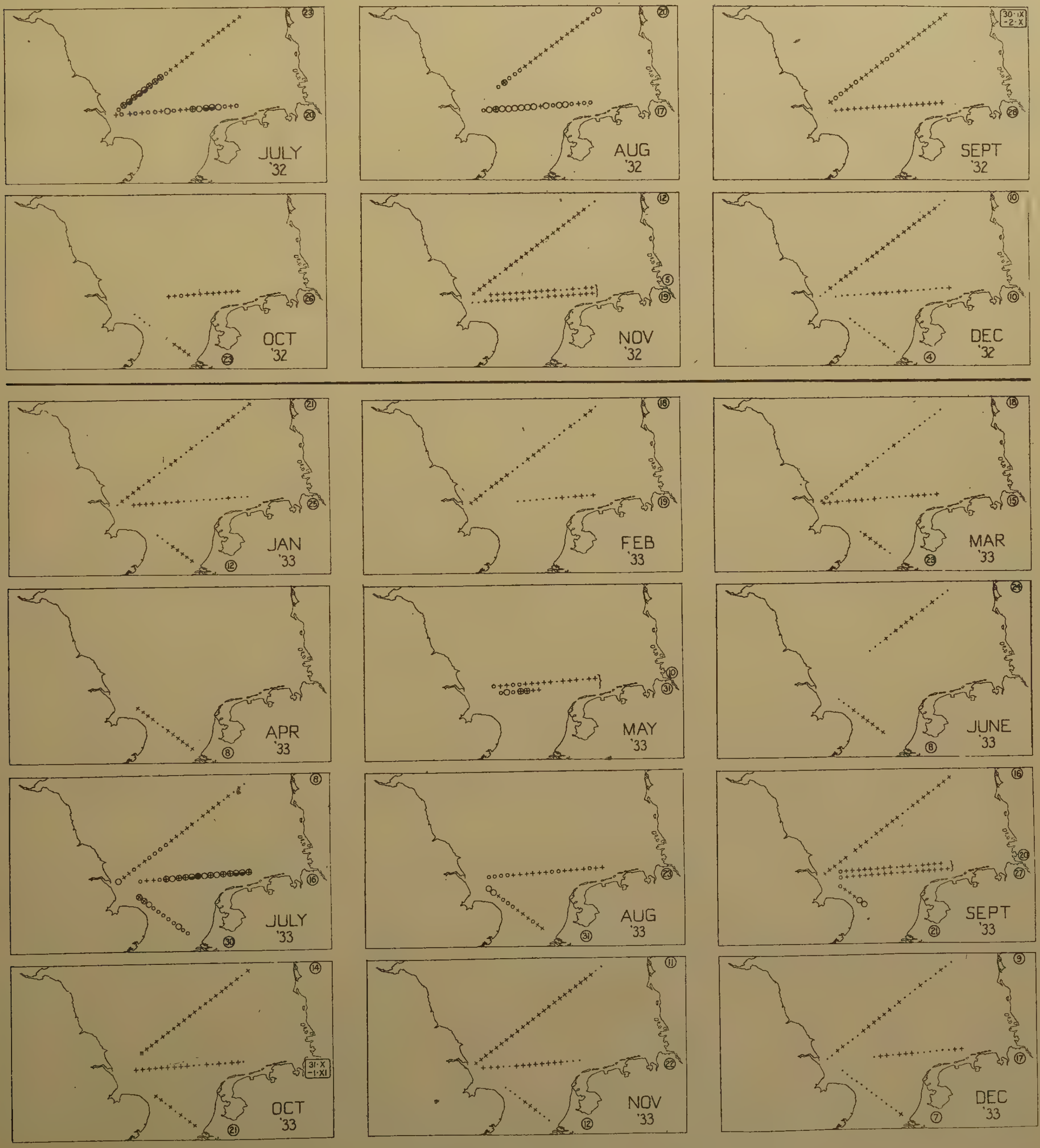

㉓
⑳
JULY
'32
㉑
⑰
AUG
'32
30·IX
-2·X
㉘
SEPT
'32
㉖
㉓
OCT
'32
⑫
⑤
⑲
NOV
'32
⑩
⑩
④
DEC
'32
㉑
㉕
⑫
JAN
'33
⑱
⑲
FEB
'33
⑱
⑮
㉓
MAR
'33
⑧
APR
'33
⑩
㉛
MAY
'33
㉔
⑧
JUNE
'33
⑧
⑯
㉚
JULY
'33
㉓
㉛
AUG
'33
⑯
⑳
㉗
㉑
SEPT
'33
⑭
31·X
-1·XI
㉑
OCT
'33
⑪
㉒
⑫
NOV
'33
⑨
⑰
⑦
DEC
'33

PLATE CXXXIX

DECAPOD LARVAE
CONTINUED

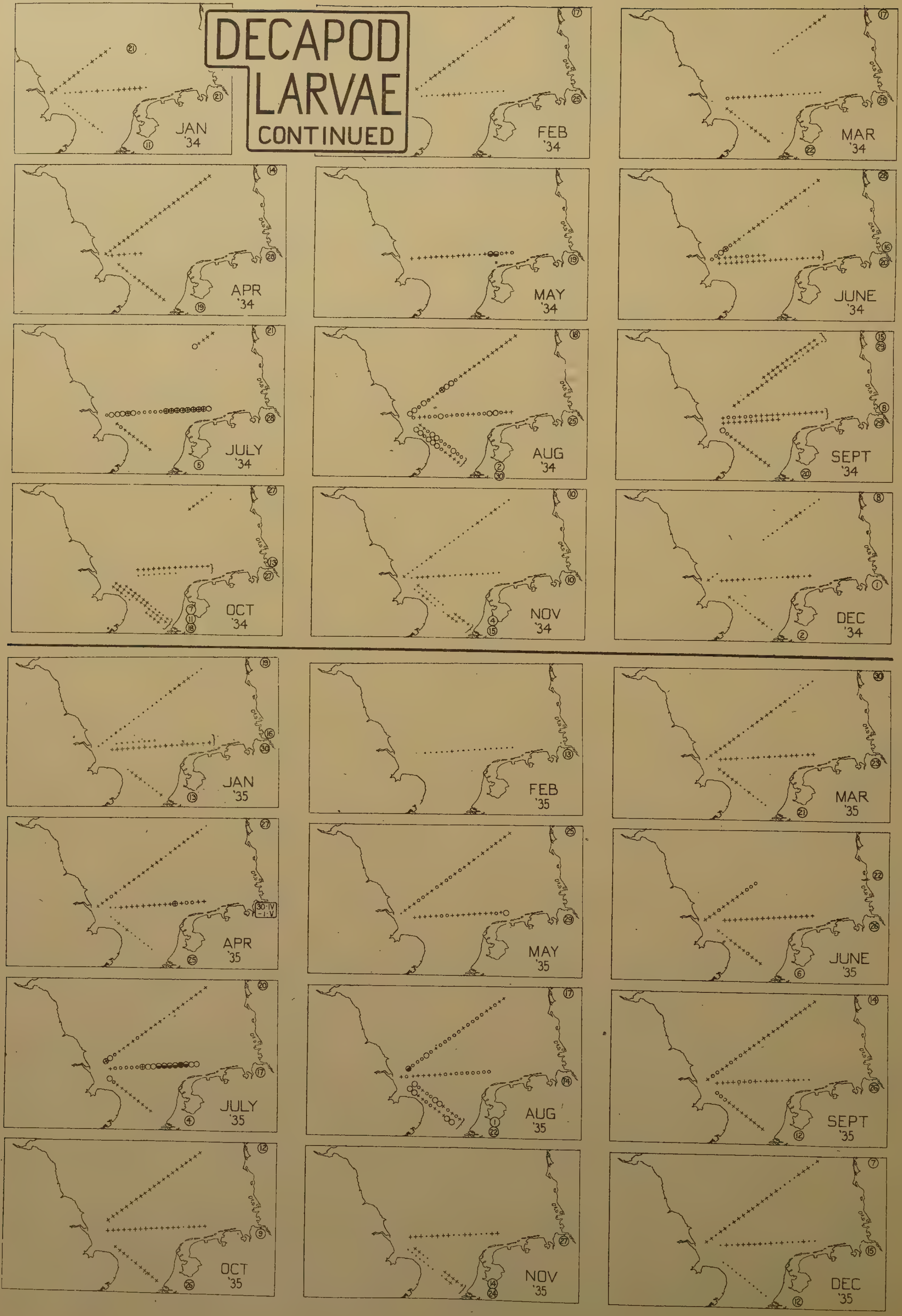

JAN '34
㉑
㉑
⑪
FEB '34
⑰
㉕
MAR '34
⑰
㉖
㉒
APR '34
⑭
⑳
⑲
MAY '34
⑲
JUNE '34
㉘
⑯
⑳
JULY '34
㉑
㉘
⑤
AUG '34
⑱
㉕
②
㉚
SEPT '34
⑮
㉙
⑧
㉙
⑳
OCT '34
㉗
⑬
㉗
⑦
⑪
⑱
NOV '34
⑩
⑩
④
⑮
DEC '34
⑧
①
②
JAN '35
⑲
⑯
㉚
⑬
FEB '35
⑬
MAR '35
㉚
㉓
㉑
APR '35
㉗
30·IV
-1·V
㉕
MAY '35
㉕
㉙
JUNE '35
㉒
㉖
⑥
JULY '35
⑳
⑰
④
AUG '35
⑰
⑭
①
㉒
SEPT '35
⑭
㉖
⑫
OCT '35
⑫
⑨
㉖
NOV '35
㉗
⑭
㉔
DEC '35
⑦
⑮
⑫

PLATE CXL

DECAPOD LARVAE
CONTINUED

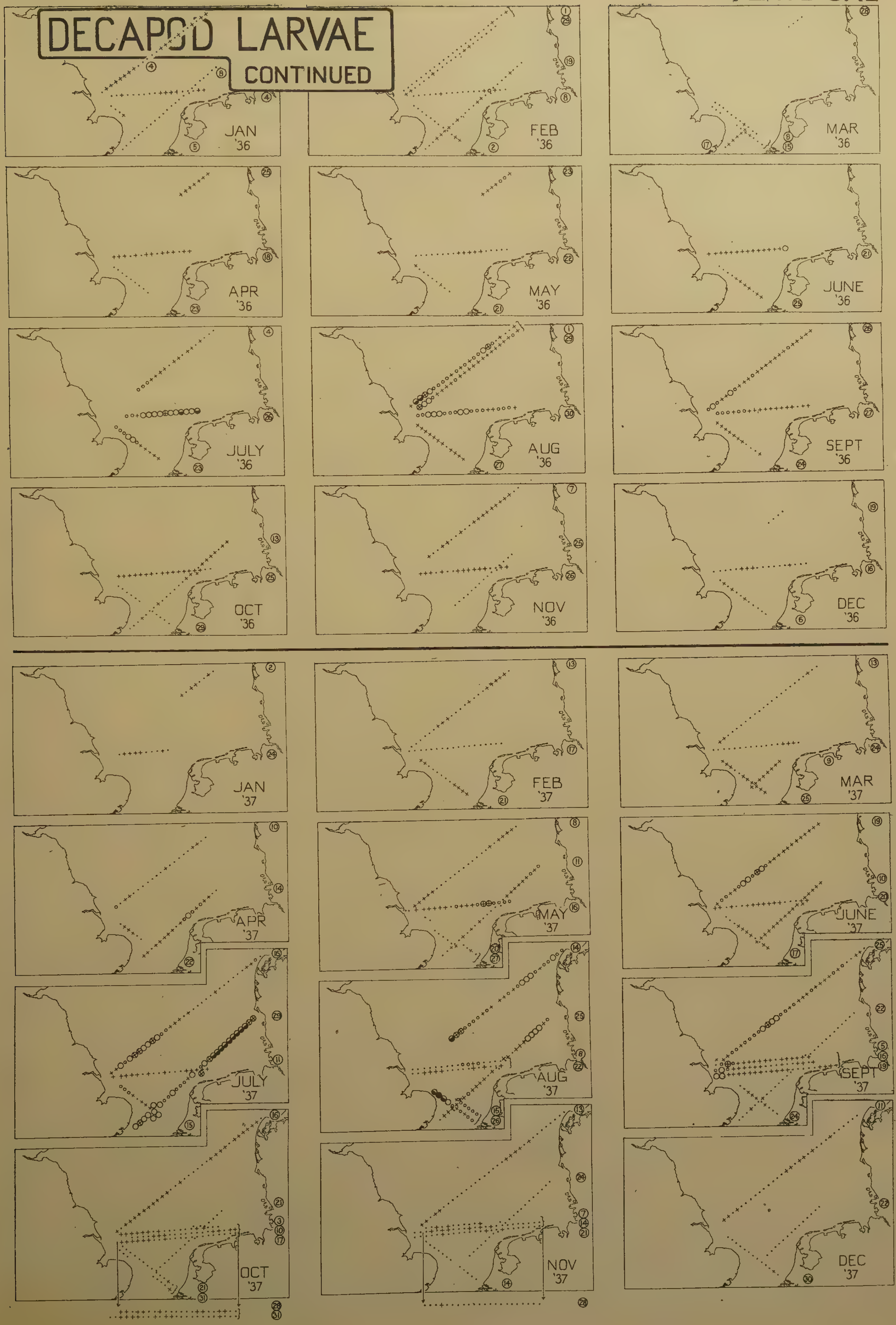
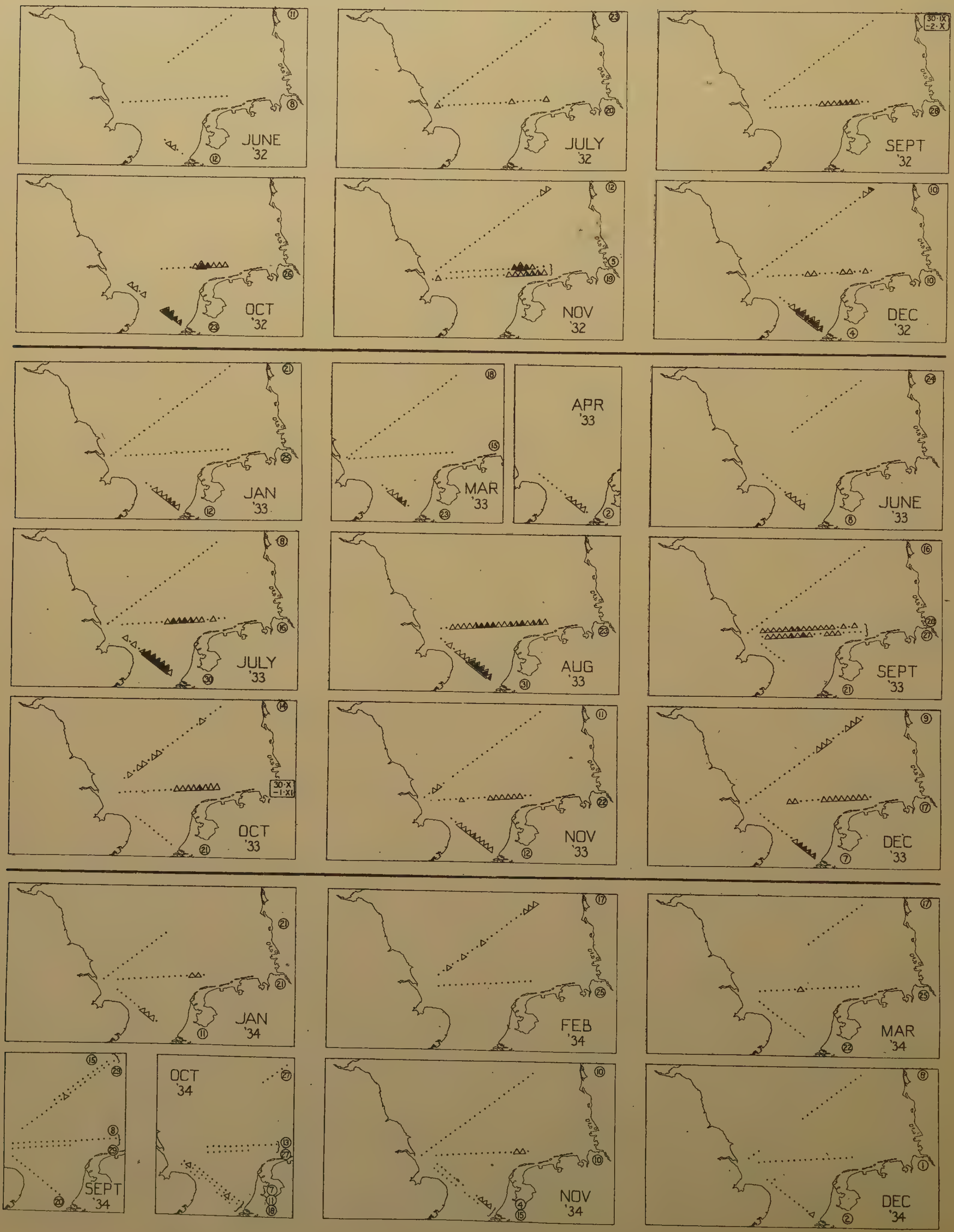

④ ⑥ ④ ⑤ JAN '36
① ㉙ ⑲ ⑧ ② FEB '36
㉓ ⑧ ⑮ ⑰ MAR '36
㉕ ⑱ ㉓ APR '36
㉓ ㉒ ㉑ MAY '36
㉑ ㉕ JUNE '36
④ ㉖ ㉓ JULY '36
① ㉙ ㉚ ㉗ AUG '36
㉘ ㉗ ㉔ SEPT '36
⑬ ㉕ ㉙ OCT '36
⑦ ㉕ ㉖ NOV '36
⑲ ⑯ ⑥ DEC '36
② ㉔ JAN '37
⑬ ⑰ ㉑ FEB '37
⑬ ㉔ ⑨ ㉕ MAR '37
⑩ ⑭ ㉒ APR '37
⑧ ⑪ ⑯ ⑳ ㉗ MAY '37
⑲ ⑩ ⑳ ⑰ JUNE '37
⑮ ㉙ ⑪ ⑮ JULY '37
⑭ ㉕ ⑧ ㉒ ⑮ ㉖ AUG '37
㉕ ㉒ ⑤ ⑯ ⑲ ㉔ SEPT '37
⑯ ㉑ ③ ⑩ ⑰ ㉑ ㉛ ㉘ ㉛ OCT '37
⑬ ㉔ ⑦ ⑭ ㉑ ⑭ ㉘ NOV '37
⑪ ㉒ ㉚ DEC '37

PLATE CXLI

CAPRELLIDAE

SCALE

△ - 1-10
◭ - 11-25
▲ - 26-50
▲ - > 50
} PER BLOCK



⑪
⑧
JUNE '32
⑫
㉓
⑳
JULY '32
30·IX –2·X
㉘
SEPT '32
㉖
OCT '32
㉓
⑫
⑤
⑲
NOV '32
⑩
⑩
DEC '32
④
㉑
㉕
JAN '33
⑫
⑱
⑮
MAR '33
㉓
APR '33
②
㉔
JUNE '33
⑧
⑧
⑯
JULY '33
㉚
㉓
AUG '33
㉛
⑯
㉖
㉗
SEPT '33
㉑
⑭
30·X –1·XI
OCT '33
㉑
⑪
㉒
NOV '33
⑫
⑨
⑰
DEC '33
⑦
㉑
㉑
JAN '34
⑪
⑰
㉕
FEB '34
⑰
㉕
MAR '34
㉒
⑮
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⑧
㉙
SEPT '34
⑳
OCT '34
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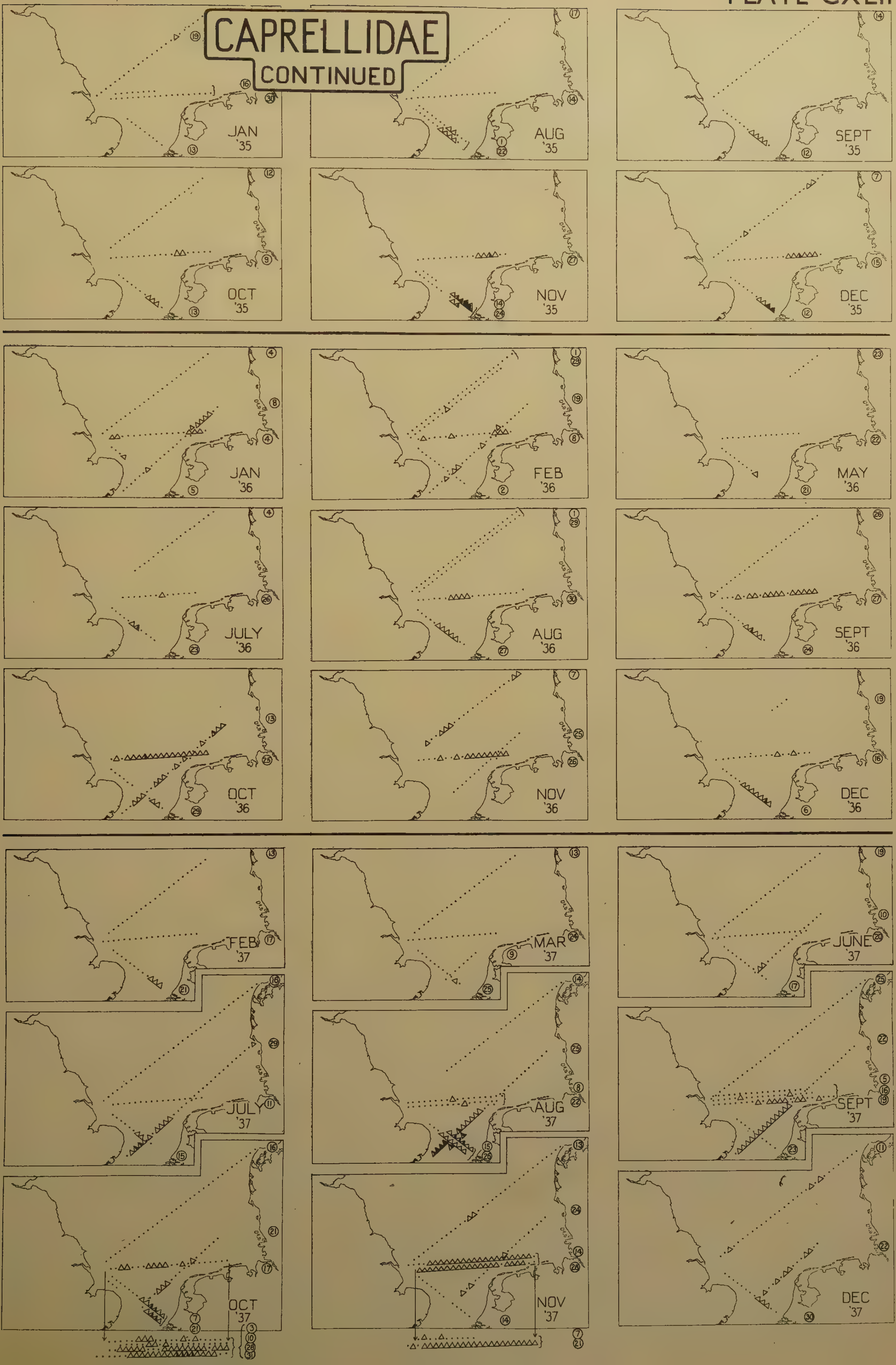
⑬
㉗
⑰
⑪
⑱
⑩
⑩
④
⑮
NOV '34
⑧
①
DEC '34
②

CAPRELLIDAE
CONTINUED


⑲
⑯
㉚
⑬
JAN
'35
⑰
⑭
①
㉒
AUG
'35
⑭
⑫
SEPT
'35
⑫
⑨
⑬
OCT
'35
㉗
⑭
㉔
NOV
'35
⑦
⑮
⑫
DEC
'35
④
⑧
④
⑤
JAN
'36
①
㉙
⑲
⑧
②
FEB
'36
㉓
㉒
㉑
MAY
'36
④
㉖
㉓
JULY
'36
①
㉙
㉚
㉗
AUG
'36
㉖
㉗
㉔
SEPT
'36
⑬
㉕
㉙
OCT
'36
⑦
㉕
㉖
NOV
'36
⑲
⑯
⑥
DEC
'36
⑬
FEB
⑰
'37
㉑
⑬
MAR
㉔
⑨
'37
㉕
⑲
⑩
JUNE
⑳
'37
⑰
⑯
㉙
JULY
⑪
'37
⑮
⑭
㉕
AUG
⑧
㉒
'37
⑮
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㉕
㉒
⑤
⑯
SEPT
⑲
'37
㉓
⑯
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⑰
OCT
'37
⑦
㉑
③
⑩
㉘
㉛
⑬
㉔
⑭
㉘
NOV
'37
⑭
⑦
㉑
⑪
㉒
DEC
'37
㉚

PLATE CXLIII

OIKOPLEURA SPP.

CONTINUED ON NEXT PLATE

SCALE

• - 0
+ - 1-5
∘ - 6-10
○ - 11-25

PER MILE PER BLOCK

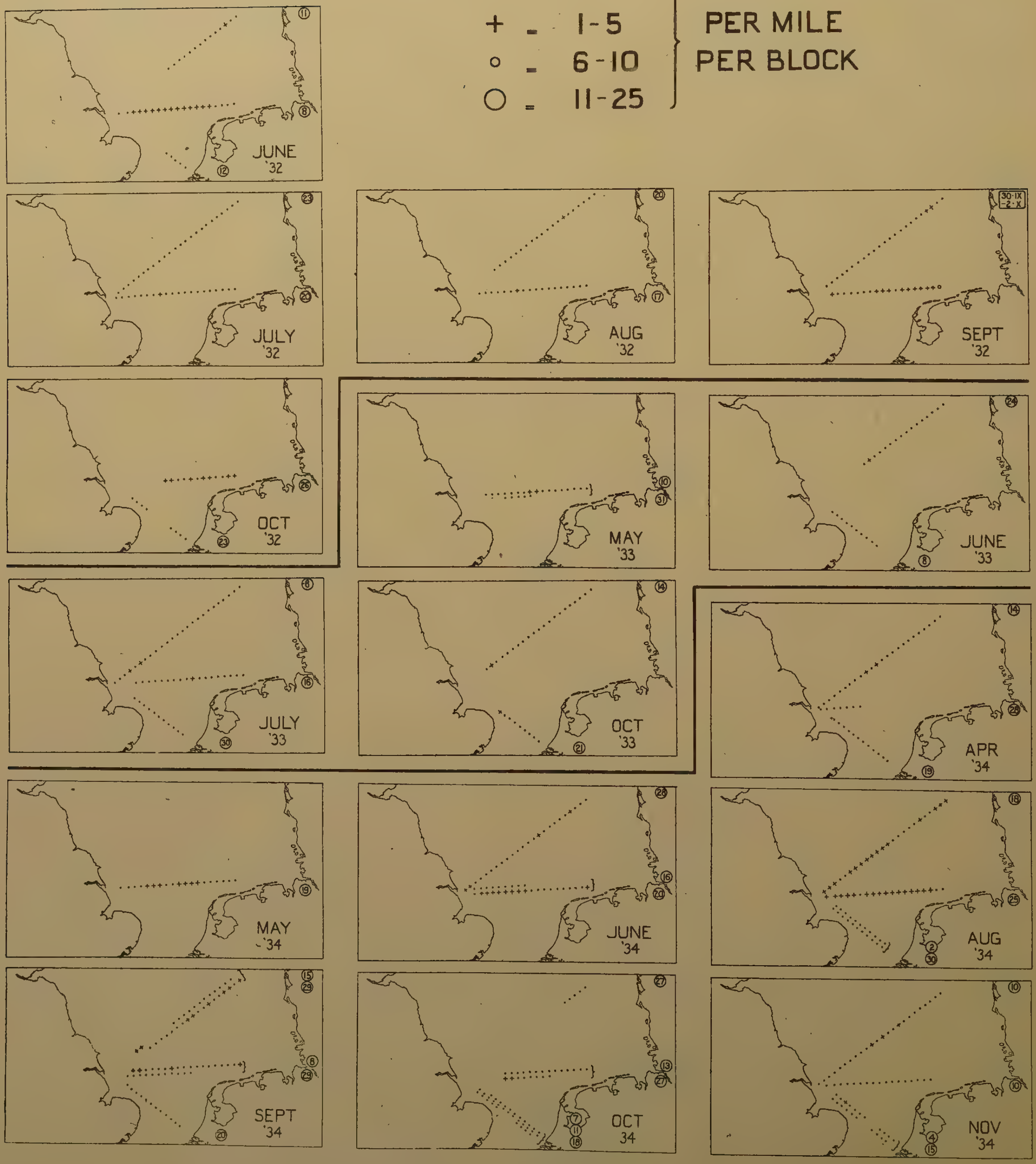

⑪ ⑧ ⑫ JUNE '32
㉓ ⑳ JULY '32
⑳ ⑰ AUG '32
30·IX -2·X SEPT '32
㉖ ㉓ OCT '32
⑩ ㉛ MAY '33
㉔ ⑧ JUNE '33
⑧ ⑯ ㉚ JULY '33
⑭ ㉑ OCT '33
⑭ ㉘ ⑲ APR '34
⑲ MAY '34
㉘ ⑯ ⑳ JUNE '34
⑱ ㉕ ② ㉚ AUG '34
⑮ ㉙ ⑧ ㉙ ⑳ SEPT '34
㉗ ⑬ ㉗ ⑰ ⑪ ⑱ OCT 34
⑩ ⑩ ④ ⑮ NOV '34

PLATE CXLIV

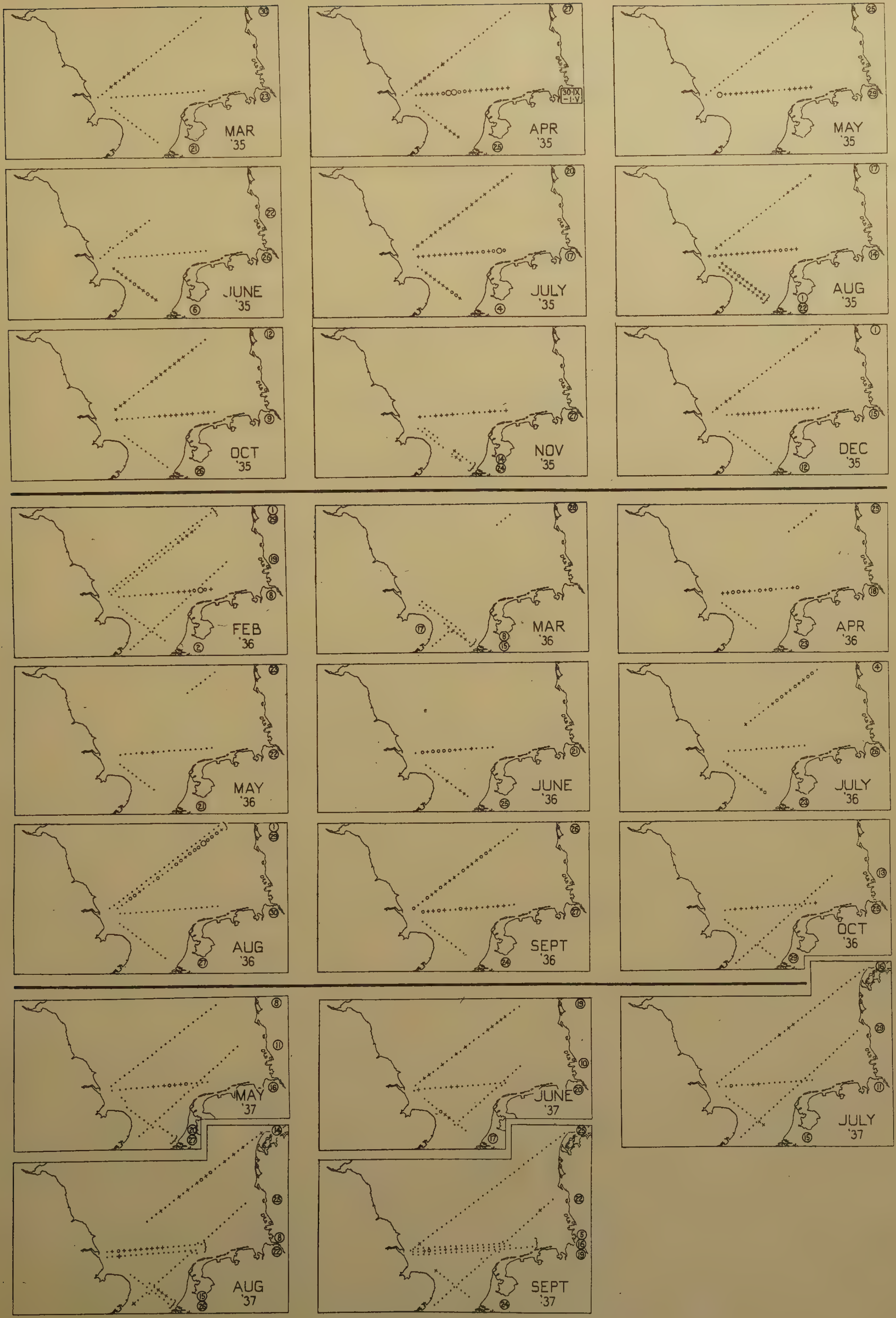

㉚ ㉓ ㉑
MAR '35
㉗ 30·IX –1·V ㉕
APR '35
㉕ ㉙
MAY '35
㉒ ㉖ ⑥
JUNE '35
⑳ ⑰ ④
JULY '35
⑰ ⑭ ① ㉒
AUG '35
⑫ ⑨ ㉖
OCT '35
㉗ ⑭ ㉔
NOV '35
① ⑮ ⑫
DEC '35
① ㉙ ⑲ ⑧ ②
FEB '36
㉘ ⑰ ⑧ ⑮
MAR '36
㉕ ⑱ ㉓
APR '36
㉓ ㉒ ㉑
MAY '36
㉑ ㉕
JUNE '36
④ ㉖ ㉓
JULY '36
① ㉙ ㉚ ㉗
AUG '36
㉖ ㉗ ㉔
SEPT '36
⑬ ㉕ ㉙
OCT '36
⑧ ⑪ ⑯ ㉔ ㉗
MAY '37
⑲ ⑩ ⑳ ⑰
JUNE '37
⑯ ㉙ ⑪ ⑮
JULY '37
⑭ ㉕ ⑧ ㉒ ⑮ ㉖
AUG '37
㉕ ㉒ ⑤ ⑯ ⑲ ㉔
SEPT '37

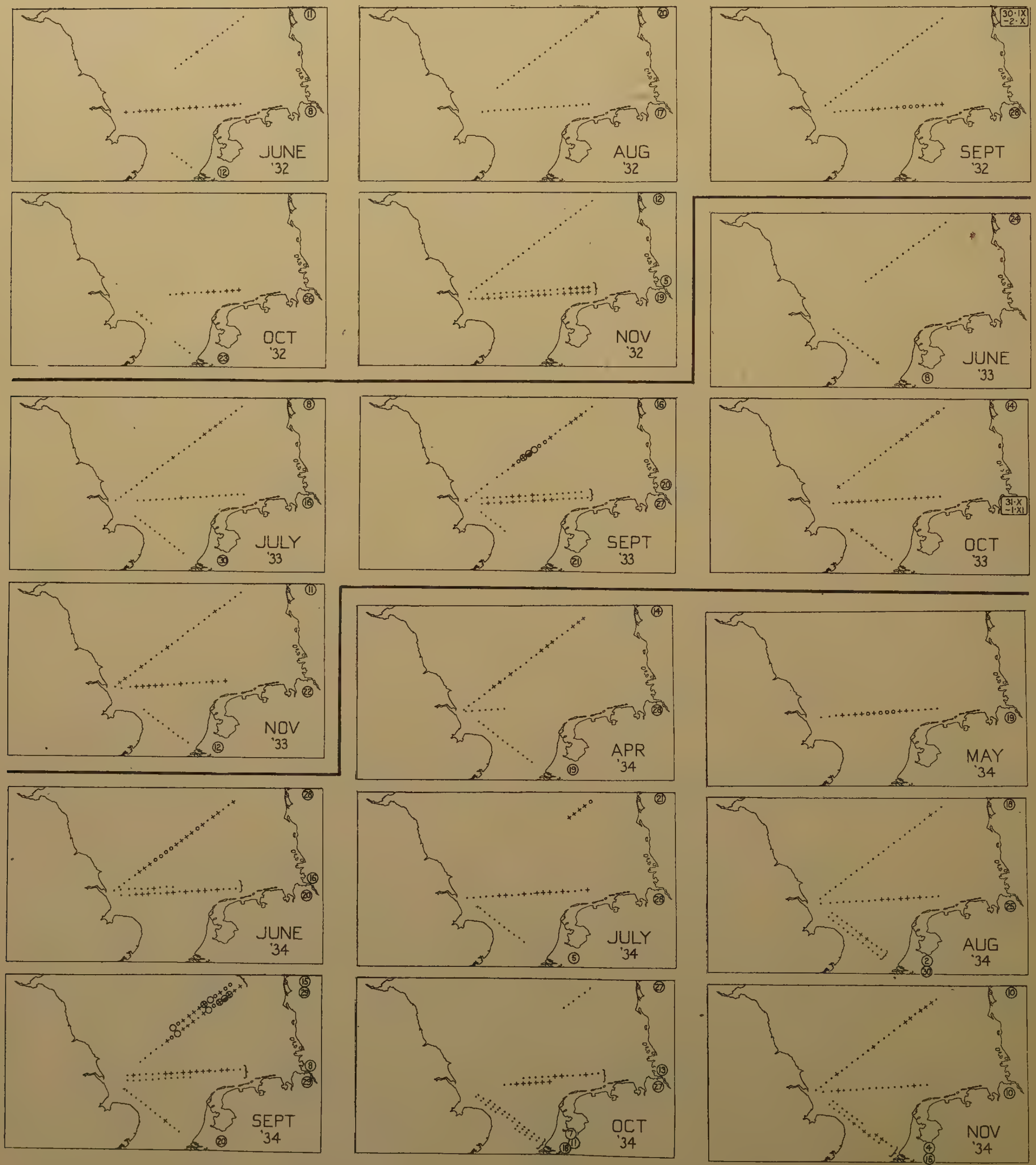
PLATE CXLV

LAMELLIBRANCH LARVAE

SCALE

• = 0
+ = 1-10
∘ = 11-25
○ = 26-50
⊕ = 51-100
◒ = 101-250

PER MILE PER BLOCK


JUNE '32
AUG '32
SEPT '32
30·IX –2·X
OCT '32
NOV '32
JUNE '33
JULY '33
SEPT '33
OCT '33
31·X –1·XI
NOV '33
APR '34
MAY '34
JUNE '34
JULY '34
AUG '34
SEPT '34
OCT '34
NOV '34

LAMELLIBRANCH LARVAE CONTINUED

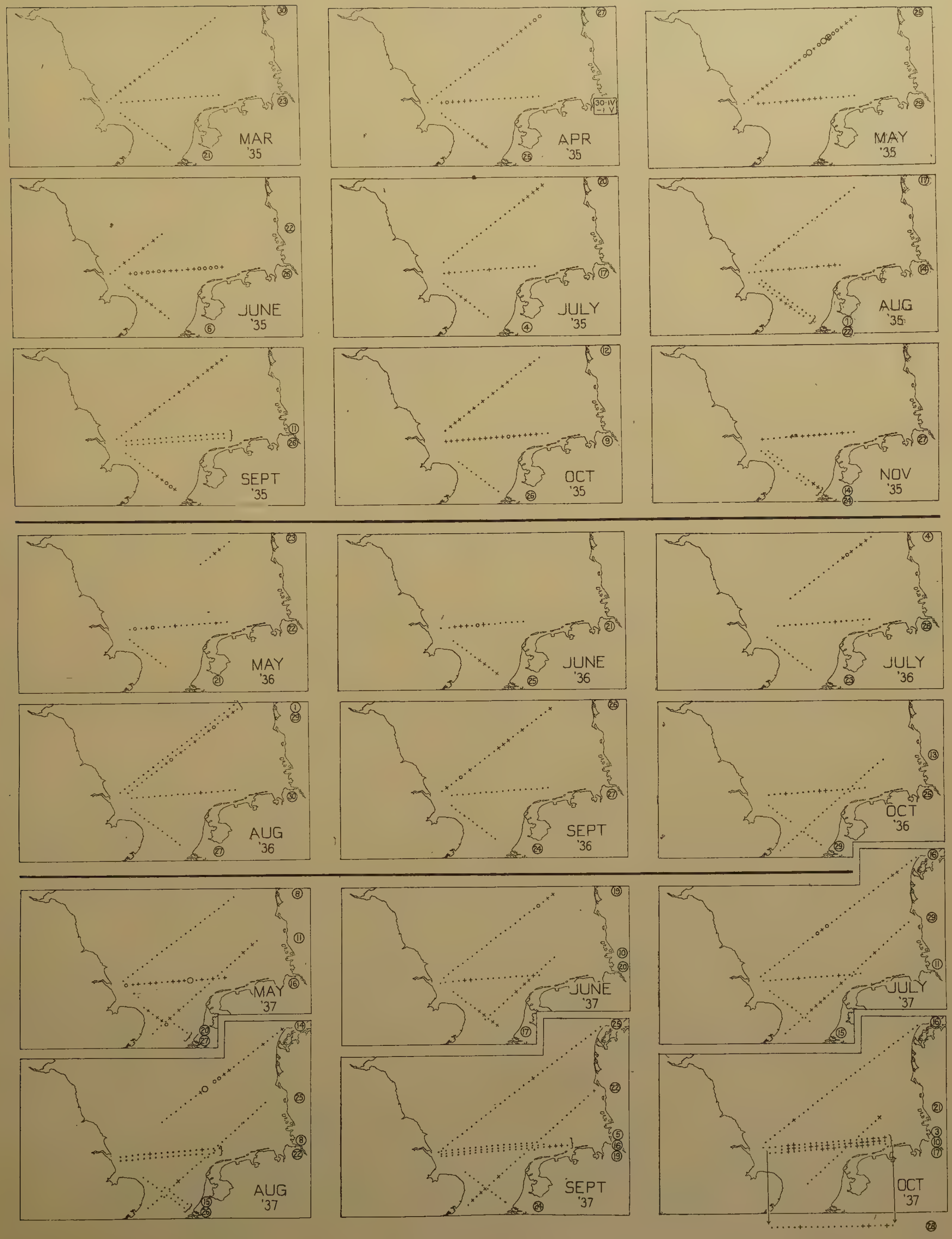

MAR '35
㉚
㉓
㉑
APR '35
㉗
30·IV –1 V
㉕
MAY '35
㉕
㉙
JUNE '35
㉒
㉖
⑥
JULY '35
⑳
⑰
④
AUG '35
⑰
⑭
①
㉒
SEPT '35
⑪
㉖
OCT '35
⑫
⑨
㉖
NOV '35
㉗
⑭
㉔
MAY '36
㉓
㉒
㉑
JUNE '36
㉑
㉕
JULY '36
④
㉘
㉓
AUG '36
①
㉙
㉚
㉗
SEPT '36
㉖
㉗
㉔
OCT '36
⑬
㉕
㉙
MAY '37
⑧
⑪
⑯
⑳
㉗
JUNE '37
⑲
⑩
⑳
⑰
JULY '37
⑯
㉙
⑪
⑮
AUG '37
⑭
㉕
⑧
㉗
⑮
㉖
SEPT '37
㉕
㉒
⑤
⑯
⑲
㉔
OCT '37
⑮
㉑
③
⑩
⑰
㉘

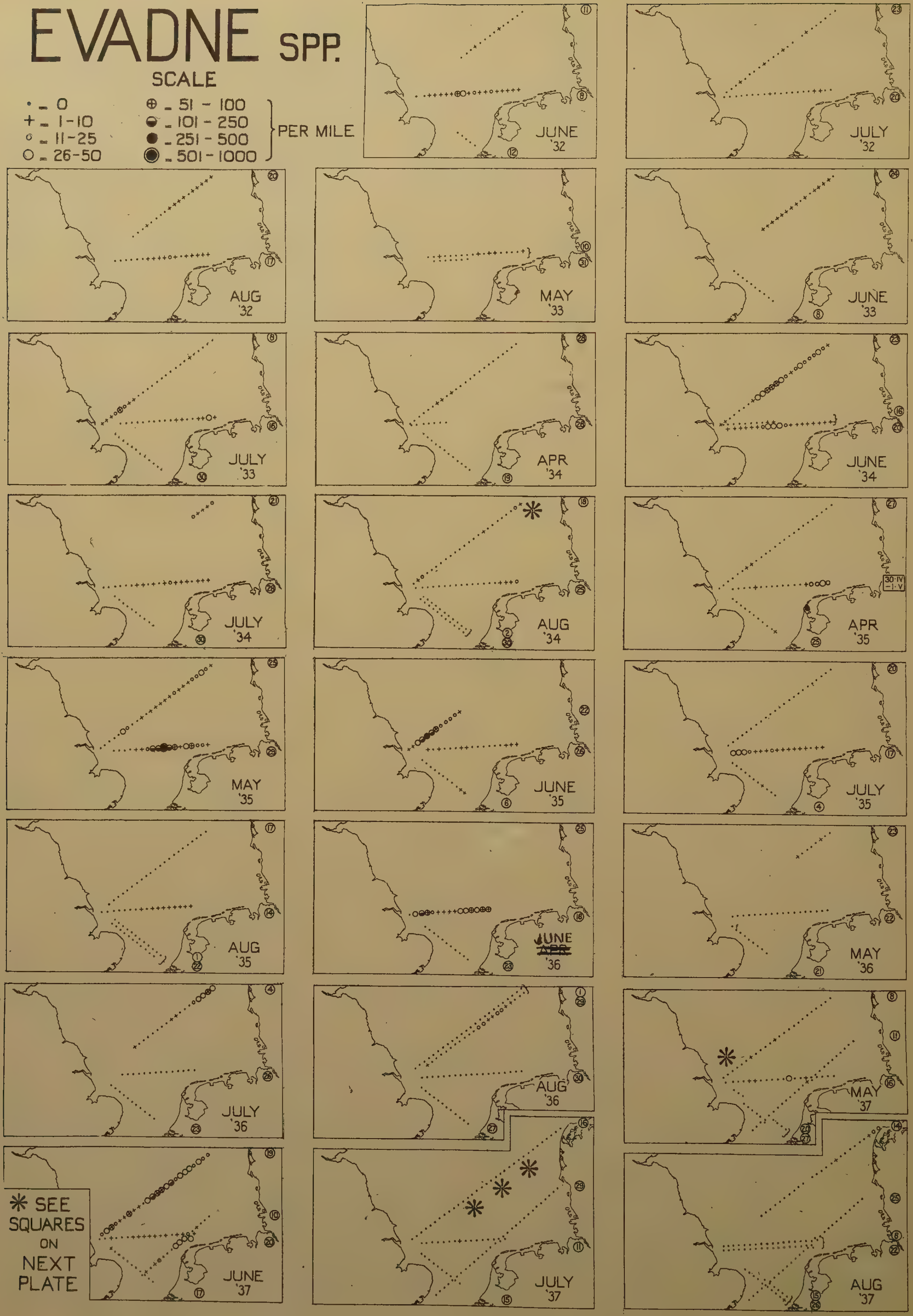
PLATE CXLVII

EVADNE SPP.

SCALE

- • – 0
- + – 1-10
- ∘ – 11-25
- ○ – 26-50
- ⊕ – 51 - 100
- ◒ – 101 - 250
- ● – 251 - 500
- ◉ – 501 - 1000

PER MILE



JUNE '32
JULY '32
AUG '32
MAY '33
JUNE '33
JULY '33
APR '34
JUNE '34
JULY '34
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JUNE ~~APR~~ '36
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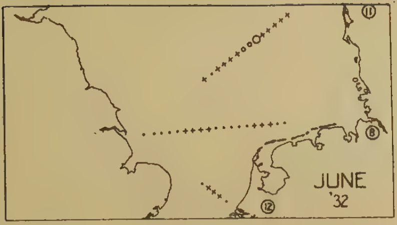
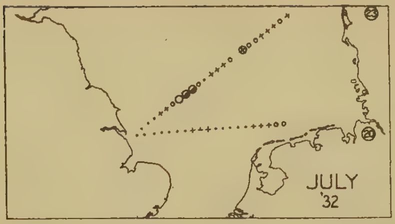
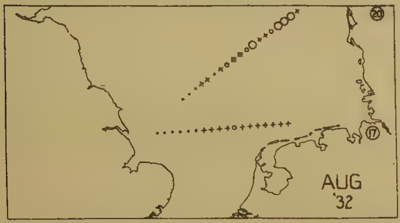
JULY '36
AUG '36
MAY '37
✳ SEE SQUARES ON NEXT PLATE
JUNE '37
JULY '37
AUG '37

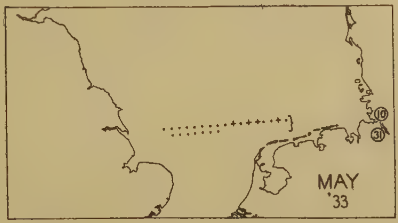
PODON SPP.

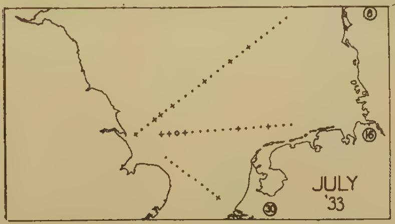
SCALE AS FOR EVADNE
EXCEPT THAT SQUARES
DENOTE CLADOCERA INDET.

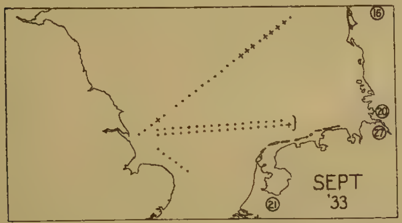








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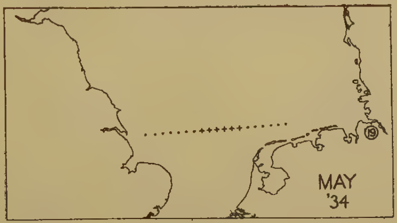

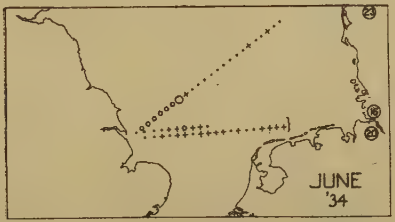

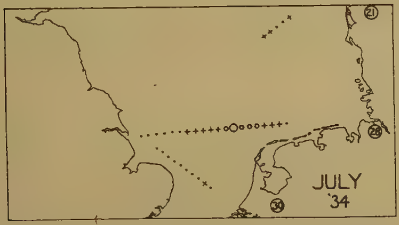

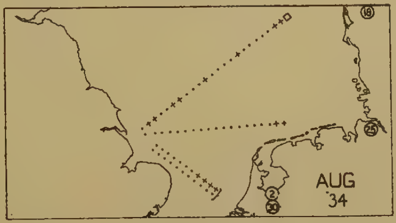

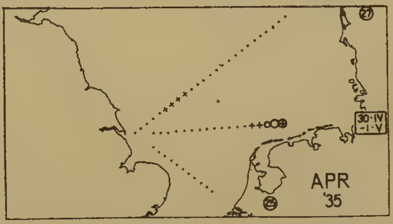
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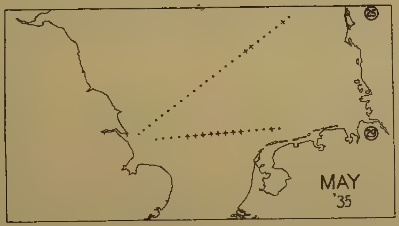

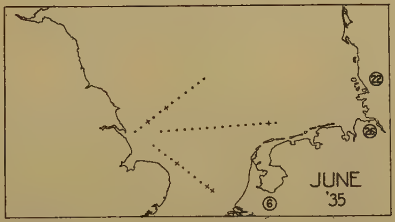

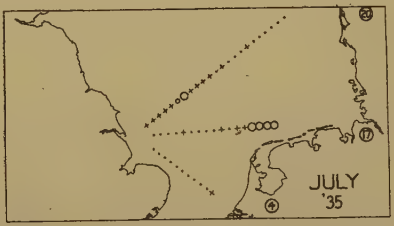

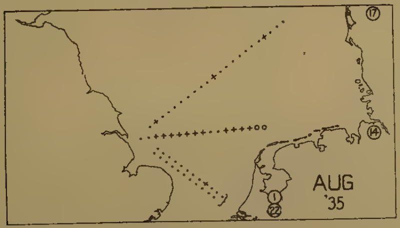

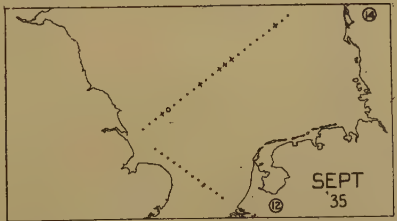

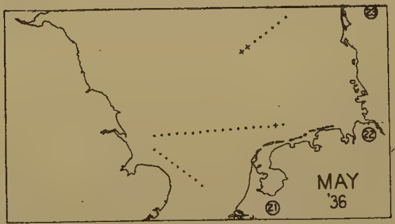

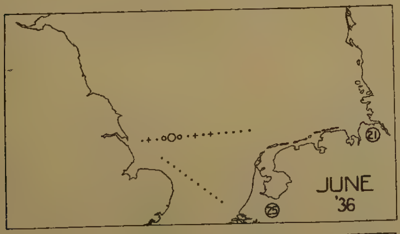

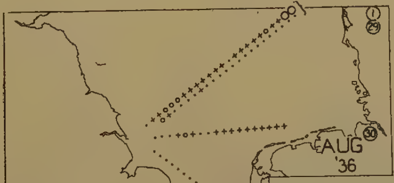

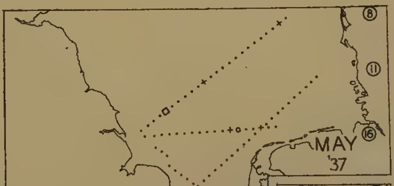
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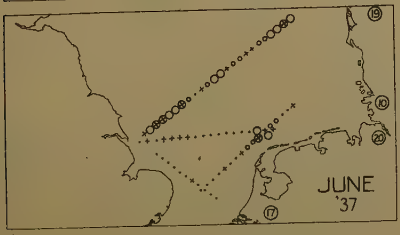
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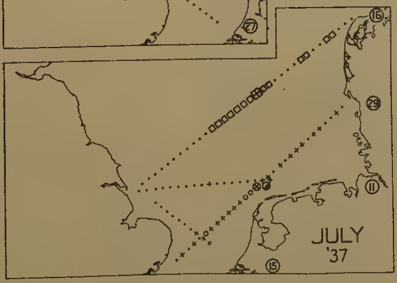
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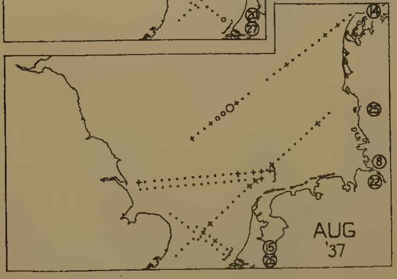
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PLATE CXLIX

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⊕ - 101-250
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● - 501-1500
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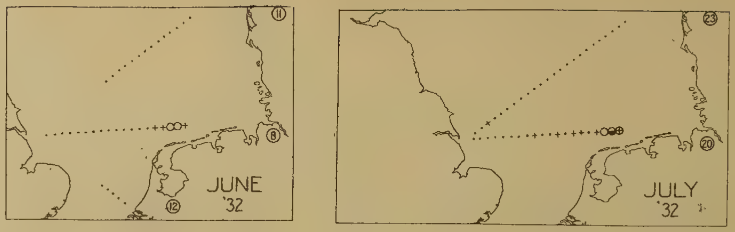

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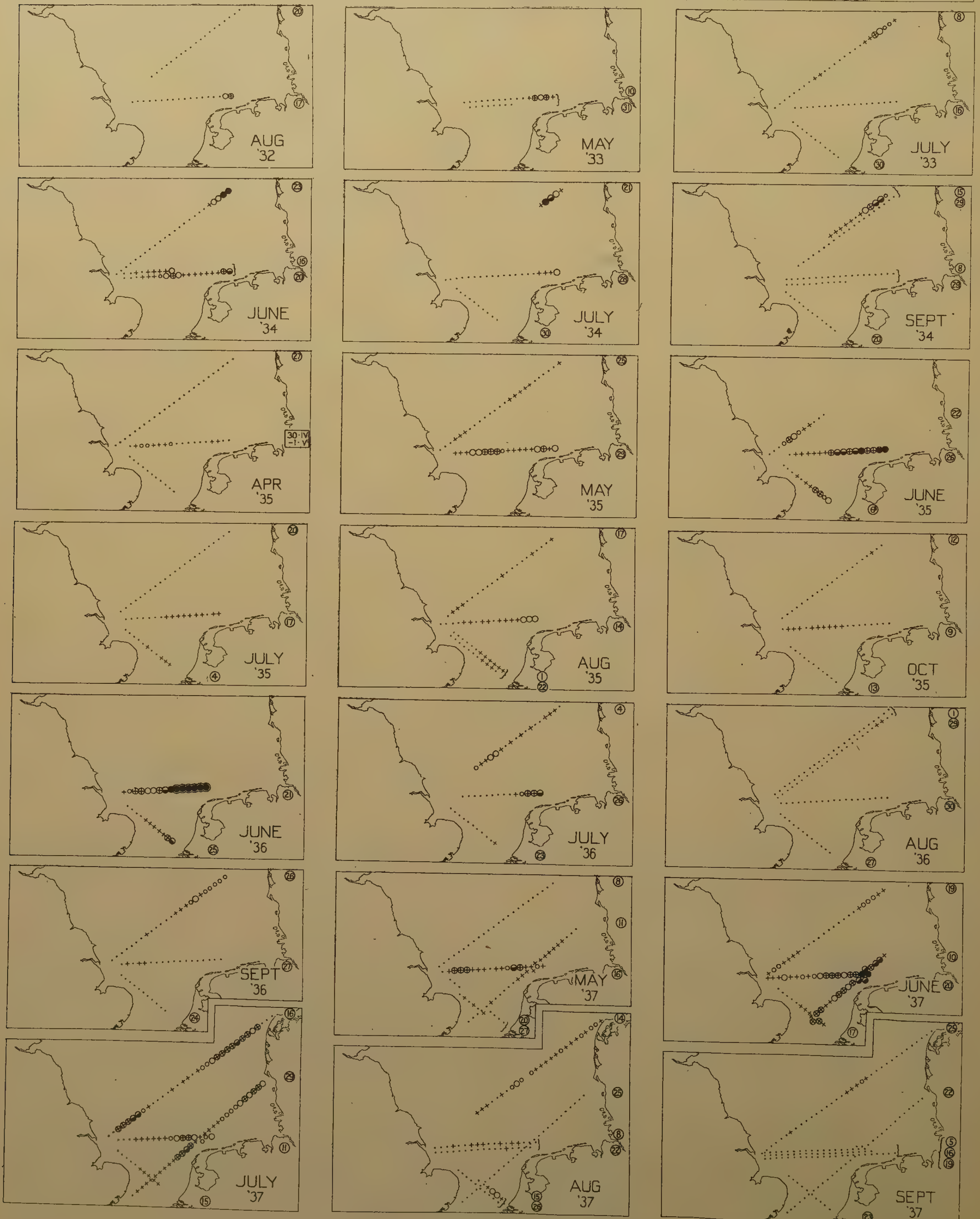

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